UNIVERSITY OF ALBERTA

REPETITIVE IMPACT TRAINING: AN INTEGRATED EVALUATION IN COMPETITIVE FIGURE SKATERS

A Multi Disciplinary Approach

By

Kelly L. Lockwood ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Doctor of Philosophy

Faculty of Physical Education & Recreation

EDMONTON, ALBERTA

Spring, 1997

0-612-21593-8

UNIVERSITY OF ALBERTA

Library Release Form

NAME OF AUTHOR: Kelly L. Lockwood

TITLE OF THESIS: Repetitive Impact Training: An integrated evaluation in competitive figure skaters.

DEGREE: Doctor of Philosophy

YEAR THIS DEGREE GRANTED: 1997

K. Lockwood

59 Middlecrest
Ancaster, Ontario L9G 2P5
CANADA

Date: April 15, 1997

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled REPETITIVE IMPACT TRAINING: AN INTEGRATED EVALUATION IN COMPETITIVE FIGURE SKATERS submitted by K. L. LOCKWOOD in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY.

Dr. A. H. Quinney (Co-Supervisor)

Dr. G. J. Bell (Co-Supervisor)

Dr. P. L. Gervais

Dr. J. D. Marshall

Dr. D. C. Cumming

Dr. P. G. Heslip

Dr. A. D. Martin (External Examiner)

Date: February, 1997

DEDICATION

To the skaters,

the coaches,

the parents,

the sport physiologists,

the national sport governing body,

& members of the skating community.

"May this work help guide athlete development in the sport of figure skating and take performance to a higher level without sacrificing the health of the athlete"

ABSTRACT

The purpose of this thesis was to describe the effects of a history of repetitive impact load-type training on the biomechanical, physiological, bone mineral density, and biochemical profiles in competitive figure skaters. A multi disciplinary approach to research was used to conduct a series of six investigations.

Chapter III describes two biomechanical analyses conducted to describe the impact nature of training in figure skating. The vertical impact forces absorbed by the skaters upon landing single, double, and triple revolution jumps were quantified. Results revealed that impact forces increased significantly with additional revolution and technical difficulty. The second kinematic analysis revealed that although, all landings of on-ice jumps are technically identical, the methods of impact absorption were significantly different.

The physiological profiles of 55 competitive figure skaters were described in Chapter IV. Autobiographical questionnaires were analysed to quantify training time and intensity, injury histories, calcium intake, and maturity status. A linear relationship was observed between technical calibre, maturation, and physiological attributes.

Projects described in Chapter V were conducted to examine the potential effects of impact load-type jump training on bone mineral density (BMD) profiles of the same skaters. These analyses revealed that skaters had significantly higher BMD measures at all sites examined. Furthermore, a sport specific comparison of the lower extremities revealed significantly higher BMD in the landing limb of all calibres of skaters.

Chapter VI hypothesized that impact load-type training may induce an adaptive response in the developing skeleton which has the potential to be observed by measuring biochemical markers of bone turnover. Three of the six markers examined: osteocalcin, PICP, and ICTP showed significant differences between calibre of skaters.

The results of this series of investigations provided insight into the significant relationships found between mechanical loading and physiological, BMD, and biochemical profiles of these athletes. These results may be used to develop guidelines for the sport of figure skating to safeguard the health of these young participants.

Key Words: Figure Skaters, Impact Loading, Physiological, Bone Mineral Density, Biochemical Indices of Bone Turnover.

ACKNOWLEDGEMENTS

The author would like to thank the following corporations for their contributions of equipment and financial support required to complete this series of investigations:

Canadian Figure Skating Association

Medical Imaging Consultants

Novel Electronics Inc.

Bone mineral data was collected and analysed by Nigel Gann, Medical Imaging Consultants. Mr. Gann's expertise contributed significantly to the successful collection of this data and was sincerely appreciated.

Bone mineral control data was obtained from the Pediatric Bone Mineral Accrual Study (1996), College of Physical Education, University of Saskatchewan. The cooperation and assistance of Dr. D. Bailey, Dr. R. Faulkner, Dr. H. McKay and Dr. D. Drinkwater in matching control data must be acknowledged.

The Faculty of Physical Education & Recreation provided ongoing financial and technical support throughout the course of this research. Without the contributions of ice time, computer assistance, and support staff this work would have not been as successful. To all of you whom assisted me in this process, I am extremely grateful.

PERSONAL ACKNOWLEDGEMENTS

To My Committee,

A committee can be defined as, "*a group of individuals joined to provide a service or function*". As a graduate student, I have had the privilege of being serviced by an extremely well educated, experienced, and sincere group of individuals. I would like to thank all the members of my committee who supported me throughout the course of these research studies.

Dr. H. A. Quinney

Dr. G. J. Bell

Dr. P. J. Gervais

Dr. J. D. Marshall

Dr. D. C. Cumming

Dr. P. G. Heslip

To my Family,

Although miles away, the distance did not interrupt the endless support I received from my family. My parents and brothers have always been a source of strength which has contributed greatly to my ability to pursue and reach my academic goals.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter Four

Chapter Five

List of Abbreviations

25 (OH) D	Twenty Five Hydroxy Vitamin D
ANOVA	Analysis of Variance
BMC	Bone Mineral Content
BMD	Bone Mineral Density
BMAD	Bone Mineral Apparent Density
Ca	Calcium
DEXA	Dual Energy X-Ray Absorptiometry
ICTP	Carboxy Terminal Telopeptide of Type I Collagen
PTH	Parathyroid Hormone
RNI	Recommended Nutrient for Canadians
OS	Osteocalcin
PICP	Carboxy Terminal Propeptide of Type I Collagen
VO_2 max	Maximum Oxygen Consumption

CHAPTER ONE

An Introduction

Introduction

In the sport of figure skating, there is a growing recognition among skaters and coaches that to be successful, an element of "risk" must be incorporated into the competitive program. "Risk" has recently been defined as, "an increase in the level of difficulty of the element being attempted" (Urton, 1995). On-ice jumping has interpreted "risk" as an increased number of revolutions or an increased number of multi-revolution jumps executed within a four or four and a half minute competitive program. To be successfully awarded for "taking a risk", skaters must demonstrate that they are striving to achieve skills demanding greater physical and technical development during both their competitive performances and their daily training.

Paralleling the increasing physical demands in this sport is the trend for children in the competitive stream of figure skating to begin serious athletic training at progressively younger ages. Coaches have adopted a "catch 'em young" philosophy which appears to be based on the supposition that early training facilitates later performance (Zauner, Maksud & Melichna, 1989). In a specialist sport such as figure skating, children in their early teens have already been undergoing intensive training and high levels of competition for four to five years. Given the repetitious and impulsive nature of their on-ice training, this surge in early participation of children has aroused interest in the ability of the skeletal structure of a child to respond and adapt to the mechanical or impact stress imposed by such training. These individuals who are training competitively during puberty are superimposing the vigorous physiological demands of impact-related activities on the biological demands of growth and development. Although the beneficial role of physical loading in the regulation of bone modelling and remodelling is commonly accepted, the type, intensity, frequency, and duration that can positively or negatively affect bone mineral accumulation is still largely unknown, especially in a physically immature population. Recently, the sophistication of biomechanical, physiological, biochemical and other laboratory techniques has allowed investigators to non-invasively define, characterize, and quantify the mechanical, physical, and biochemical responses of bone to such stimuli.

Several recent studies have provided support for the theory that bone turnover was directly related to mechanical influences as experienced in sporting events (Chilibeck *et al.*, 1995; Fehling *et al.*, 1995; Heinonen *et al.*, 1995; Heinonen *et al.*, 1993; 1995; Kirchner *et al.*, 1995; McCulloch *et al.*, 1992; Grimston *et al.*, 1991;1993; Wolman *et al.*, 1991; Bailey & McCulloch, 1990). However, it has also been suggested that unwise training practices inducing excessive mechanical stress have the potential to produce a breakdown in the musculo skeletal system (Grimston & Zernicke, 1993). Training is designed to create stresses on the body and thus promote an adaptation response. However, there is little information regarding the exact response of growing bone to various magnitudes of loads. Few studies have shown the adaptation of immature bone to stressful exercise or sport specific loading and the resultant spectrum of anatomic and patho anatomic changes (Ruiz *et al.*, 1995; Bailey, 1994; Slemenda *et al.*, 1994; Grimston *et al.*, 1992; 1993). Currently, the potential for injury to the growing tissues with possible long term implications is a concern for coaches, parents and athletes.

The on-ice training regimes inherent to the sport of figure skating are largely comprised of repetitive impact load-type activities. Competitive figure skaters routinely engage in these activities 3-6 hours per day, 6-7 days per week (Ferstle, 1979; Niinima, 1982; Smith & Micheli, 1982). During this time, they repeatedly land from jumps or throws of multi-revolutions and various heights. A particularly difficult jump or throw may often be attempted 20-100 times in a single practice session. It was theorized that the resultant ground impact forces upon landing from on-ice jumps produce high levels of potentially damaging stress. Therefore, the primary concern arising as a consequence of intensive figure skating training is the potential for impact related injuries. Specifically, the emphasis on triple revolution jumps, which are now commonly performed at the junior level, warrants concern. Pre-pubescent and pubescent athletes participating in such intensive impact related training may be predisposed to training induced bone trauma. Thus, the focus of this research is to descriptively profile athletes with a history of repetitive impact load-type training. As a result, the following questions could be addressed: Does intensive impact load type training pose risks for growing athletes? Can adverse effects or effects that predispose the athletes to long-term consequences be expected with this type of training during the growth years? If so, should the amount of training and competition be limited for young athletes?

In addition, while it is likely that the type of physical activity in which competitive figure skaters engage provides a mechanical stimulus to bone mineralization, a high percentage of these athletes may also engage in behaviours that theoretically would have a negative influence on bone mineral density (BMD). Although factors related to bone health have been extensively examined in some subgroups of athletes such as female runners, bone health and related issues in figure skaters have been largely ignored.

Data comparing the physiological and biochemical profiles of competitive athletes whose training regimes employ different types of skeletal loading are sparse. Investigating the profiles of figure skaters and their sport specific type of training has potential importance for furthering our understanding of bone for at least two reasons. First, figure skaters regularly expose their skeletal structures to mechanical forces which have been demonstrated to be moderately high (Lockwood & Gervais, 1995). Second, since the evaluation of the physique is an integral component in judging performance, competitive figure skaters live in a subculture that places a premium on being lean. This is supported by reports suggesting that figure skaters have a high prevalence of symptoms related to disordered eating (Smith, 1994).

In conclusion, current research is beginning to elucidate training regimes that have positive versus negative effects on skeletal tissue, but assessing the impact of training on a young population has clearly been lacking. The growing number of young athletes participating in such training and the limited research information has not yet provided conclusive answers. It is hypothesized that beginning high intensity training during the first and second decade of life may place repeated mechanical loads on bones that lack the structural maturity to adapt adequately. However the effects of these loads have not been quantified. Therefore, the relationships between bone health, skeletal maturity, and training merits further investigation.

Statement of the Problem

Technical development in the sport of figure skating has placed greater physical demands on athletes at progressively younger ages. However, research examining the effects of these demands on the physiological and biological health of these athletes has not been thoroughly investigated. Understanding the nature of adaptation to the stresses imposed on the human body by training is essential to guide the development of the athlete and appropriate training programs. A particular concern is the potential to impose stresses to which the body cannot adequately adapt. In the sport of figure skating, the requirement for young developing athletes to master jumping techniques is critical to their future competitive career. Yet, it is entirely possible that the repetitive practising of jumps may be contraindicated because of the potential inability of bone to withstand and adapt to this chronic stress.

Justification for the Study

The importance of examining the effects of training exhibited by these athletes cannot be understated. This investigation presents a complex interplay of mechanical, physiological, and biochemical mechanisms with no one factor being singled out as the primary cause. Although recent evidence has suggested that athletic training regimes may contribute significantly to bone density, a trend toward lower bone densities among those with the greatest training volume has also been identified (Slemenda *et al.*, 1993). The question of where there is a point of diminishing returns must be addressed. Thus, it is important that current research explore extensively the underlying etiology of this phenomenon.

Study Objectives

A/ To quantify the impact forces upon landing single, double, and triple revolution jumps absorbed by figure skaters training at a competitive calibre.

B/ To isolate the contribution of landing technique and equipment (ie., skate structure) in impact absorption.

C/ To describe and examine the relationships between mechanical loading and the physiological, bone mineral density, and biochemical profiles of an impact trained group of competitive figure skaters.

Statistical Hypotheses

A/ Impact forces increase with technical difficulty of jumping skills.

B/ Technique and skates contribute significantly to the characteristics of impact absorption.

C/ (i) Physiological, biochemical, and bone mineral density profiles of figure skaters will be related to technical calibre of training.

(ii) BMD profiles will be significantly different than normative data, consisting of a non trained control group.

Study Delimitations and Limitations

A/ Study Delimitations

a) Subjects consisted of male and female figure skaters, ranging in age from 10-26 years and of four successive technical calibres (juvenile, novice, junior, and senior competitive skaters).

Inclusion criteria:

a) Subjects had a minimum competitive history of three years.
b) Subjects had no history of metabolic bone disorders.
c) Subjects were injury free for six months prior to and during testing.

d) For the bone mineral density analyses, controls were drawn from a pre-existing data pool of matched subjects.

e) Normative values of biochemical indices were taken from the most current literature.

B/ Study Limitations:

a) The study was limited to competitive figure skaters training in the Edmonton area and currently competing at a juvenile through to a senior national calibre.

b) Control data was limited to the bone mineral density project only (Chapter Vb).

c) Factors that could not be empirically controlled but were considered in the interpretation of this evaluation were as follows: (i) maturational status, (ii) nutritional status, (iii) training intensities/activity levels (other than training), and (iv) injury history.

d) The reliability of the above inventories as research tools have been questioned by some investigators due to the tendency of subjects to under or overestimate values.

e) Bone mineral density (BMD), bone mineral content (BMC) and biochemical markers (PTH, Os, 25-OH-D, ICTP, PICP, Ca) were not used as outcome variables, but rather components of the global description of figure skaters with a history of repetitive impact load-type training.

The aim of the proposed study was to quantify the impact loads inherent in training competitive figure skaters and test the hypothesis that impact load-type training induces an adaptation in bone which may be monitored by measuring bone mineral density (BMD) or biochemical markers of bone turnover. Furthermore, none of the previous studies correlating bone mineral density (BMD) to physical activity conclusively considered training, maturation, nutrition, and biochemistry and therefore the bone differences observed remain without adequate understanding. This series of studies was proposed to elucidate our understanding of the effects of impact loading in figure skaters.

References

Bailey, D. (1994). Invited Paper: Physical activity and the attainment of peak bone mass in children. *The Australian Journal of Science and Medicine in Sport*, 26(½):3-5.

Bailey, D. & McCulloch, R. (1990). Bone tissue and physical activity. *Canadian Journal of Sport Sciences*, 15(4): 229-239.

Chilibeck, P., Sale, D. & Webber, C. (1995). Exercise and bone mineral density. *Sport Medicine*, 19(2): 103-122.

Fehling, P., Alekel, L., Clasey, J., Rector, A. & Stillman, R. (1995). A comparison of bone mineral densities among female athletes in impact loading and active loading sports. *Bone*, 17(3): 205-210.

Ferstle, J. (1979). Figure skating: in search of the winning edge. *The Physician and Sportsmedicine*, 7(2): 129-133.

Grimston, D., Engsberg, J., Kloiber, R. & Hanley, D. (1991). Bone mass, external loads and stress fracture in female runners. *International Journal of Sport Biomechanics*, 7: 293-302.

Grimston, S., Morrison, K., Harder, J. & Hanley, D. (1992). Bone mineral density during puberty in Western Canadian children. *Bone & Mineral*, 19: 85-96.

Grimston, S., Willows, N. & Hanley, D. (1993). Mechanical loading regime and its relationship to bone mineral density in children. *Medicine & Science in Sports & Exercise*, 25(11): 1203-10.

Grimston, S. & Zernicke, R. (1993). Exercise-related stress responses in bone. *Journal of Applied Biomechanics*, 9: 2-14.

Hickey, J. (1980). The effects of compensatory pronation on the competitive ice skater. In Rinaldi, R. R., & Sabie, M.L. (Eds.), *Sports Medicine '80*, Futura Publishing Company, Mt. Kisco, New York: 169-183.

Heinonen, A., Oha, P., Kannus, P., Sievanen, H., Haapasalo, H., Manttari, A. & Vuori, I. (1995). Bone mineral density in female athletes representing sports with different loading characteristics of the skeleton. *Bone*, 17(3): 197-203.

Heinonen, A., Oja, P., Kannus, P., Sievanen, H., Manttari, A. & Vuori, I. (1993). Bone mineral density of female athletes in different sports. *Bone & Mineral*, 2: 1-14.

Heinonen, A., Oja, P., Kannus, P., Sievanen, H., Haapasalo, H., Manttari, A. & Vuori, I. (1995). Bone mineral desnity in female athletes representing sports with different loading characteristics of the skeleton. *Bone*, 17(3): 197-203.

Kirchner, E., Lewis, R. & O'Connor, P. (1995). Bone mineral density and dietary intake of female college gymnasts. *Medicine & Science in Sports and Exercise*, 27: 496-502.

Lockwood, K. & Gervais, P. (1995). Quantification of impact forces upon landing single, double, and triple revolution jumps in figure skaters. Conference Proceedings of the XVth International Society of Biomechanics (ISB), Jyvaskyla, Finland.

Nigg, B. & Herzog, W. (1994). Biomechanics of the Musculo Skeletal System. John Wiley & Sons Publishers, Toronto.

Niinimaa, V. (1982). Figure skating: What do we know about it? *The Physician and Sports Medicine*, 10(1): 51-56.

McCulloch, R., Bailey, D., Whalen, R., Souston, C. Faulkner, R. & Craven, B. (1992). Bone density and bone mineral content of adolescent soccer athletes and competitive swimmers. *Pediatric Exercise Science*, 4: 319-330.

Ruiz, J., Mandel, C. & Garabedian, M. (1995). Influence of spontaneous calcium intake and physical exercise on the vertebral and femoral bone mineral density of children and adolescents. *Journal of Bone and Mineral Research*, 10(5): 675- 682.

Slemenda, D., Reister, T., Hui, S., Miller, J., Christian, J. & Johnson, C. (1994). Influences on skeletal mineralization in children and adolescents: Evidence for varying effects of sexual maturation and physical activity. *Journal of Pediatrics*, 125: 201-207.

Slemenda, D. & Johnson, C. (1993). High intensity activities in young women; site specific bone mass effects among female figure skaters. *Bone and Mineral*, 20: 125-132.

Smith, A. (1994). Figure Skating. In R. Agnostini (Eds.), *Medical and Orthopaedic Issues of Active and Athletic Women*. Hanley & Belfus, Inc., Philadelphia: 388-394.

Smith, A. & Micheli, L. (1982). Injuries in competitive figure skaters. *The Physician and Sports Medicine*, 10(1): 36-47.

Urton, E. (1995). What is risk? How, as competitive judges, do we evaluate risk? *Skaters Edge*, Fall Issue: 4.

Wolman, R., Faulman, L., Clark, P., Hesp, R. & Harries, M. (1991). Different training patterns and bone mineral density of the femoral shaft in elite, female athletes. *Annals of the Rheumatic Diseases*, 50: 487-489.

Zauner, C., Maksud, M. & Melichna, J. (1989). Physiological considerations in training young athletes. *Sports Medicine* , 8(1): 15-31.

CHAPTER TWO

Review of Literature

Theories of Mechanical Loading on Bone

Considerable evidence has indicated that bone is a multi-functional dynamic structure, that is sensitive and highly responsive to biomechanical, biochemical, and biological stimuli (Bailey & McCulloch, 1990). In humans and other vertebrates, bones have predominantly three functions: (i) as structural organs, providing mechanical strength and stability, (ii) as major organs for calcium homeostasis and storage of phosphate, magnesium, potassium, and bicarbonate, and (iii) as sites for haemopoiesis. The growth, development, and maintenance of the skeletal structure is affected by several factors including genetics, nutrition, hormones, drugs, and mechanical forces. Each may work separately or in combination to cause normal or abnormal development.

Mechanical loads acting on these structures have been identified as the primary stimuli in maintaining and/or increasing the mass and strength of bone. According to Price *et al.* (1995), the responsiveness of bone to changes in mechanical environment ensures that bone mass and architecture are appropriate for the loads it is required to withstand. Studies using animals and humans have shown that mechanical loading of bone leads to increased bone mass while reducing the mechanical load results in a loss of bone mass (Bailey & McCulloch, 1990; Burger & Veldhuijzen, 1993; Forwood & Burr, 1993; Leuken *et al.*, 1993; LeVeau Bernhardt, 1984; Smith & Gilligan, 1991). An animal model, developed by Glucksmann (1939) as cited by Burger & Veldhuijzen (1993) investigated the stress effects in bone. He cultured several chick embryo bone rudiments together in such a position that, because of their growth in length during culture, pressure was exerted on each other. Increased tension caused by the rudiment bending, seemed to enhance bone formation locally, while tension reduction on the concave side of the rudiment inhibited ossification. These observations indicated that skeletal cells are sensitive to mechanical stress and respond to altered stress by production of an altered intercellular matrix (Burger & Veldhuijzen, 1993). Although the studies by Glucksmann did not allow any quantification of the forces evoked in vitro, the importance of their observation was that they showed that bone cell differentiation does react to mechanical stress. Several other authors have since confirmed this work and coined strain or stress as the key intermediate variable between loading forces and bone remodelling (Frost, 1973; Martin & McCulloch, 1987; Lanyon, 1993).

In humans, the two dynamic conditions of bone are termed modelling and remodelling. The influence of mechanical stress on these conditions was reviewed by Bailey & McCulloch (1990) and summarized as follows. Modelling is described as the process most active during growth, resulting in the alteration of size and shape through formation on one surface and resorption on another surface. Remodelling is a renewal process resulting in the continual breakdown and reformation of old bone. It is estimated that 10% - 30% of the skeleton is replaced by remodelling in each year of human life (Aloia, 1989).

Investigations conducted by Frost (1973) have characterized some of the specific qualities and effects of strain on the processes of bone modelling and remodelling. Frost (1973) developed the theory of the "Mechanostat" which states that some minimum effective or dynamic strain (MES_m) must be exceeded in order to initiate the modelling process and thus potentiate an increase in bone mass. It was also Frost (1973) who suggested and Hert *et al.* (1971) who first demonstrated that it is dynamic, not static strain which influences bone modelling/remodelling activity.

Theories presented by Lanyon (1993) concur with the earlier theories of Frost (1973), claiming that it is not only a MES_m but also a cyclic feedback system of alternating strains that enhances bone gain/loss. Figure 2.1 illustrates a schematic, developed by Lanyon, representing how the functional strain at each location within the bone may be achieved and maintained as a result of a classical feedback loop. Unaccustomed high loads produce strains above the optimal level resulting in an osteogenic response which increases bone mass and reduces the functional strains. Strain levels below the optimal level produce a conservational and potentially osteogenic stimulus which is insufficient to prevent hormonally mediated bone loss (Lanyon, 1993). This continues until bone mass is reduced and the strain increases sufficiently to establish a new equilibrium. The conservational and osteogenic response may be a dose-related expression of the same stimulus, or separate responses to separate stimuli (Lanyon, 1993).

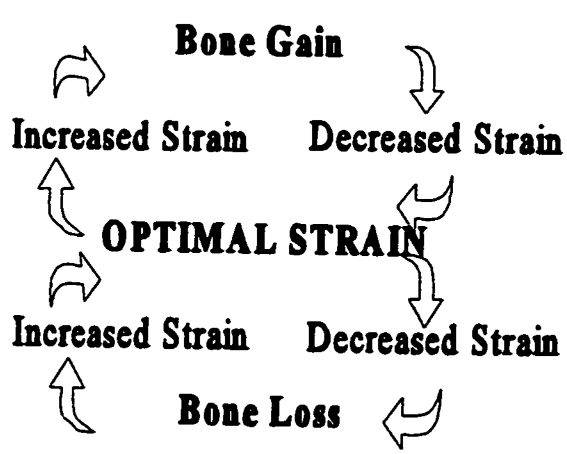


Figure 2.1 Lanyon's (1991) model of the classical feedback loop of optimal bone strain.

What is currently unknown are the exact signals and potential thresholds of strain required by the human skeletal system to trigger or evoke these processes. Furthermore, it is unclear whether or not there is a threshold between positive and negative strains and what exactly is the threshold at which bone fatigues or breaks down as a result of physical overload. Although several questions remain unanswered, possible interactions between mechanical loading or stress, hormonal responses, genetics, maturity, nutrition, and possibly disease and related drug interventions, working separately or in combination, have been identified as pieces of the puzzle that facilitate the health and growth of skeletal structure and integrity.

Effect of Physical Activity on Bone

Over the past 10 years, improved technology for bone mass measurements and biochemical analysis in humans has allowed a tremendous growth in clinical research into the responses of bone. The effect of physical activity on bone health and integrity has been extensively studied in both athletic and non athletic populations (Bailey, 1994; Grimston *et al.*, 1991;1992;1993; Heinonen *et al.*, 1993;1995; Kannus *et al.*, 1994; Margulies *et al.*, 1986; Nichols *et al.*, 1994; Robinson *et al.*, 1995; Slemenda & Johnson, 1993 Slemenda *et al.*, 1991;1994). Several recent review articles (Chilibeck *et al.*, 1995; Forwood & Burr, 1993; Suominen, 1993; Smith & Gilligan, 1991; Bailey & McCulloch, 1990) have presented summaries of the research to date examining the effects of physical activity, exercise or impact load-type activities on bone from three different perspectives: (i) a mechanical perspective quantifying the effects of different magnitudes of impact on bone mineral density or bone mass, (ii) a biochemical perspective examining the underlying responses causing resorption and formation of bone, and (iii) a hormonal perspective investigating the interaction which triggers communication and disruption in the endocrine system. The general consensus from the results of these studies suggested that physical activity has the potential to influence the development of bone mass, although several of the reports have questioned the degree and direction of the specific influence. Documentation supporting the osteogenic effects of physical loading in the regulation of bone modelling and remodelling is commonly accepted. However the type, intensity, frequency and duration of the exercise that best enhances bone mineral accumulation are still undefined. Research findings have been somewhat controversial and confounded by extraneous variables.

To date, few studies have examined and controlled for physiological, biochemical, and biological responses to a specific intervention. It is suggested that because of the complexity of mechanical loading inherent in a wide range of activities and the possible interactions with respect to maturation, fitness level, and nutritional status of the individual, threshold levels of activity associated with positive or negative changes in bone are unfounded.

Mechanical Loading in Sport

Several authors have postulated that athletes have significantly denser bones than non-athletes and associated this result with the mechanical loading inherent in physical activity and muscular development (Fehling *et al.*, 1995; Heinonen *et al.*, 1993: 1995; Kirchner *et al.*, 1995; Kannus *et al.*, 1994; Sievanen *et al.*, 1994; Slemenda *et al.*, 1993; Grimston *et al.*, 1991; Snow-Harter *et al.*, 1990; Pirnay *et al.*, 1987). According to

Nichols *et al.* (1994), athletes are generally stronger and tend to have more lean tissue mass than non-athletes and as a result would be expected to have higher bone densities than sedentary individuals. Based upon Frost's theory of "Mechanostat", this would suggest that if a particular physical activity or sport is to have a greater potential for maximizing bone mineral density, it should require movements that produce strains on bones that exceed the MES_m at any given time.

By contrasting the bone mineral densities of athletes participating in sports of differing impact magnitudes, it has been generally accepted that mechanical loading in sport has the potential to influence bone development and integrity, however the authors cited have questioned the dose-response relationship. Appendix A presents a list of the most recent, as well as the classic investigations, examining bone mineral densities in athletes representing a variety of sport loading histories. Nilsson & Westlin (1971) were the first to show that athletes participating in various sports have higher bone mineral densities than biological age, race, and gender matched non-athletes. They hypothesized that mechanical loading, as experienced in sport, has the potential to stimulate bone mass. This work has been supported by several more recent investigations, however there is considerable variability in the magnitude and significance of the differences observed between athletes and non-athletes depending on age, gender, type of sport and training, bone site under investigation and finally the methodology employed to obtain the data. As illustrated, studies have elected to comment upon a selected number of variables and neglected to take into account or comment upon the interacting factors.

The theory of a greater magnitude of impact having a more pronounced effect on

BMD has been descriptively demonstrated by studies comparing athletes participating in sports of differing loading characteristics and magnitudes (Fehling *et al.*, 1995; Robinson *et al.*, 1995; Grimston *et al.*, 1993; Heinonen *et al.*, 1993;1995; Wolman *et al.*, 1992; Snow-Harter *et al.*, 1990. These cross sectional studies have reported higher BMD and BMC in athletes than sedentary controls and higher in impact loaded sports (eg., gymnastics) than in other unloaded sports (eg., swimming).

Fehling *et al.* (1995) compared BMD of collegiate female athletes who competed in impact loading sports, volleyball (n=8) and gymnasts (n=13), to a group of athletes who participated in an active loading sport, swimming (n=7) and a group of controls (n=17). Bone mineral density, body composition, and menstrual history were evaluated. BMD in the impact loaded groups were significantly higher than the swimmers and controls. No difference was found between the swimmers and controls. Furthermore, the prevalence of oligo/amenorrhea in the gymnastic group did not appear to negatively influence the BMD.

Heinonen *et al.* (1995) completed a similar study comparing 59 Finnish female athletes representing three sports, aerobic dancers (n=27), speed skaters (n=14), and squash players (n=18). This design also included two control groups, physically active referents (n=25) and sedentary controls (n=25). Training history, calcium history, menstrual status, and fitness parameters were also assessed. The squash players had the highest values for weight adjusted bone mineral density at all sites. Aerobic dancers and speed skaters also had significantly higher BMD values at loaded sites than the controls. The results also supported the concept that training, including high strain rates in versatile movements and high peak forces was effective in enhancing bone formation. Calcium levels did not appear to affect BMD at any skeletal site.

Robinson *et al.* (1995) investigated bone mass and oligomenorrhea and amenorrhea in two groups of competitive female athletes with different skeletal loading patterns, gymnasts (n=21) and runners (n=20) compared to controls (n=19). The prevalence of oligo- and amenorrhea was 47% for gymnasts, 30% for runners and 0% for controls. BMD of gymnasts was significantly higher than runners and controls despite the higher incidence of menstrual dysfunction. Similar to the previous studies, dietary calcium did not differ among the groups. The authors concluded that the mechanical forces generated from high impact loading and muscular contraction during gymnastic events had an effect which appeared to counteract the increased bone resorption that has been previously shown to result from oligo- and amenorrhea. The underlying reason for this outcome is presently unclear and the hormonal link could not be explained by the authors. However it was suggested that a dose-response relationship between intensity of impact and hormonal response may exist. Ott (1991) speculated that although activity and estrogen are related, the mechanisms of their beneficial effects on bone are probably competitory. Mechanical loading may increase bone formation, whereas estrogen decreases bone resorption and may be anabolic during bone development.

A common shortcoming of the descriptive studies discussed was their inability to quantify the impact dosage and further establish a dose-response relationship. A unique study conducted by Bassey & Ramsdale (1994) experimentally examined the effect of impact loading using a controlled intervention design. Healthy premenopausal women were randomized into control and test groups to determine if regular bouts of a quantified duration and intensity of impact loading would produce increases in bone density in a six month period. Their results provided evidence that only weight bearing activity, including high impact exercises, was sufficient to produce improvements in BMD.

Magnitude of loading can also be expressed by the muscles exerting forces upon the skeleton. Exercising muscles may exert a very local effect on the highly stressed parts of the skeleton. Studies by Snow-Harter *et al.* (1990) revealed that muscle strength and mass are significantly related to BMD. It appears that at least part of the increased bone mass of stronger individuals can be attributed to increased skeletal loading by stronger and heavier muscles. Although support for the notion that individual muscles groups influence the skeletal areas to which they attach is limited, this theory was confirmed by the site specific studies conducted by Kannus *et al.* (1994); Pirnay *et al.* (1987); and Slemenda & Johnson (1993). Slemenda & Johnson (1993) identify the potential mechanisms for increasing skeletal densities in ice skaters to include repetitive practice of impact loaded activities such as jumping and the use of the same muscle groups producing large forces on the skeleton. Research examining relationships between strength and jumping ability in figure skaters examined by Lockwood & Sovak (1993) revealed significant correlations of lower body strength with increasing jumping ability. It could therefore be suggested that both the additional strength required to execute jumps of greater revolutions and the magnitude of impact forces absorbed upon landing jumps of greater revolutions contribute to increased skeletal densities in the lower extremities.

It has also been hypothesized that the training response of different skeletal sites varies according to the sport-specific loading. Site specific positive effects on bone mass in elite athletes have been reported in the lower extremities of figure skaters, forearms of tennis players and parallel negative effects have been observed in hemiplegia, comparing the affected to the unaffected limbs. Studies conducted by Slemenda *et al.* (1993) revealed that the BMD of the lower extremities in figure skaters is significantly higher than a sedentary control group, however there was no significant difference in upper extremity BMD. Pirnay *et al.* (1987) designed a study which controlled for the controversial issues of genetics, nutrition, and maturation, using each subject as their own control. By comparing dominant to non-dominant limbs, Pirnay *et al.* (1987) was able to confirm the effects of site specific loading. It may be concluded that the osteogenic effects of training are specific to the skeletal sites where mechanical strains occur.

In addition to the magnitude of the load and active musculature influencing the mass of healthy bone, it has also been recognised that the osteogenic effects of training are probably quite specific to the frequency, the number of cycles of loading, and the skeletal sites where the mechanical strain occurs. Lanyon & Rubin (1984) noted that a light repetition of moderate exercise is sufficient to obtain stimulation of osteogenesis and an increase in bone mass. Although previous studies cited indicated that the BMD of runners was significantly lower than weight lifters, gymnasts, and figure skaters, runners were still higher than controls or sedentary individuals. For example, it has been demonstrated that the stimulus provided by lower intensity repetitive impact activities, such as running, does not produce the same osteogenic outcomes as sport of greater impact magnitudes, such as gymnastics or figure skating (Robinson *et al.*, 1995). However, if too excessive, loading may also predispose micro- or macro-damages to the skeletal structure. In contrast, athletes participating in repetitive impact-loaded activities in which they have introduced trauma (ie., stress fractures), have been described as having greater site specific BMD and BMC values. Therefore, the dilemma of how to determine how much is too much exists.

In contrast to the potentially positive effects of mechanical loading, Grimston *et al.* (1991) investigated the relationship between BMD in runners with and without a history of stress fractures. In contrast to what may be expected, runners with a history of stress fractures had higher BMD of the lower extremities. A kinematic analysis revealed that these runners experienced increased loads during running, however the mechanics of their running techniques were not examined. The question of whether greater forces are the cause or consequence of runners having suffered stress fractures could not be explained by the authors. This study was unique in that it addressed the potential harmful effects or risks associated with mechanical loading in sport. Although epidemiological studies have been conducted on the incidence of injuries in sport, investigation into the cause of injury specifically with regard to high or repetitive mechanical loading may provide further insight.

Research investigating the biochemical responses of loading and unloading on bone are sparse, especially in humans. However, a foundation in animal models has been recently established. Price *et al.* (1995) tested the hypothesis that exercise induces an adaptive response in the developing skeleton which may be monitored in vivo by measuring biochemical markers of bone metabolism in horses. The effects of exercise on two biochemical markers of bone formation were determined; carboxy terminal propeptide of type I collagen (PICP) and the bone specific isoenzyme of alkaline phosphatase (BAP), and one marker of resorption, the pyridinoline crosslinked telopeptide domain of type I collagen (ICTP). The results of these assays for bone resorption and formation indicated that the treadmill exercise regimen used for this study resulted in a general increase in bone turnover in 2 year old thoroughbreds. Price *et al.* (1995) concluded by stating that these findings indicated that biochemical marker determination may provide a sensitive, non invasive method of monitoring skeletal turnover during athletic training.

Nichols *et al.* (1994) assessed the effect of a 27 week gymnastics training program on bone mineral density, body composition, insulin-like growth factor and osteocalcin on 11 female gymnasts and 11 controls. Although osteocalcin values were significantly higher in gymnasts than the controls, no differences were found over training.

Preliminary investigations examining the potential roles of three biochemical markers (parathyroid hormone, osteocalcin and 25-hydroxy vitamin D) in detecting bone trauma in response to repetitive impact loading in three calibers of competitive figure skaters revealed that calibre of skater, age and PTH were significantly correlated ($p \leq 0.05$) (Lockwood & Bell, 1993, Unpublished findings). Although this finding could be partially explained by the negative relationship which exists between PTH and age (Benucci et al., 1993), the trends found among the other variables warranted further investigation.

In conclusion, positive relationships appear to exist between exercise and bone mineral density although the exact frequency, duration, and intensity of exercise needed for a significant impact have not been clearly identified. It has been suggested that the complicating effects of genetics, diet, and metabolism usually encountered in cross sectional reviews can be eliminated in sport studies involving unilateral activities such as tennis (Bailey & McCulloch, 1990). As stated previously, the mechanical control of bone remodelling and the specific relationships between loading and bone mineral density are unclear. One reason for this lack of understanding is that the functional input (activity engendered strain in the bone) is difficult to assess. Studies in vivo on the relation between amount of mechanical loading and skeletal quantity have been complicated by the complexity. To study the processes whereby skeletal tissue reacts to mechanical stress, experimental systems are required that allow direct measurement of cell proliferation, differentiation, and matrix metabolism under controlled loading conditions (Burger & Veldhuijzen, 1993). Exercise or sport related studies have been limited to using non-invasive measurements of bone and estimated measurements of loading relating the levels of physical activity or changes in the level of activity, to assessments of bone mass architecture. As a result, investigations using physical activity and specific sporting events have been plagued with methodological shortcomings.

Bone Mineral Density Studies on Children in Sport

Pediatric studies of mechanical influences on bone have focused almost exclusively on a diseased population. Although evidence supporting the effects on the mature skeleton have been relatively convincing, BMD studies in children and adolescents have been limited by methodological concerns such as high radiation exposure and relatively long scanning times. More recently, advanced technology and the use of X-ray sources of bone mineral assessment have made these studies more permissible.

During skeletal maturation two distinct skeletal processes occur. First the process of bone growth, which functions to increase tissue volume thereby achieving adult size, and second the process of modelling, which under the influence of local factors such as mechanical loading alter the tissue components to produce macro-architectural features. To optimize bone mass during skeletal maturation, the process of modelling must be optimized (Grimston *et al.*, 1993). Appropriate mechanical loading during the critical period of rapid skeletal growth and modelling in children would therefore appear important. Lanyon (1993) supports the theory suggesting that the consequences of a lack of functional input are different at different stages of growth and development. For example, if loading is reduced during growth formation, bone is stimulated less and it does not develop its full normal proportions. However, in order to quantify the effects of any intervention, the effects of normal growth and maturation should be initially identified.

Studies of bone growth and development have been conducted to monitor changes in BMD and BMC in maturing individuals to determine specifically at what age peak bone mass can be influenced to its greatest extent and what factors are important for optimal skeletal maturation. Of the studies cited in Appendix B, (Zanchetta *et al.*, 1995; Faulkner *et al.*, 1993; Kroger *et al.*, 1992; Bonjour *et al.*, 1991; Katzman *et al.*, 1991 Southard *et al.*, 1991; Glastre *et al.*, 1990) all revealed that dramatic increases in BMD are demonstrated during puberty. These authors agree that total bone mass and bone mineral density increase during the growing years, reaching a peak in early adulthood and, following a transient period of stability, age related loss of bone begins. Bonjour *et al.* (1991) revealed that during puberty, the accumulation rate in BMD in the lumbar spine and femoral neck increased 4-6 times over a 3-4 year period, in both females and males, respectively. However, females have higher values of BMC than males from 12-14 years of age and boys have higher BMD than girls in groups older than 15 years of age. As stated by Zanchetta *et al.*(1995) this pattern parallels the difference in age of onset of puberty of males and females. This difference appears to be essentially due to a more prolonged bone maturation period in males versus females, with a larger increase in bone size and cortical thickness. Studies conducted by Faulkner *et al.* (1993), Katzman *et al.* (1991), and Glastre *et al.* (1990) also suggested that BMD increases most rapidly during the early teens and gender related periods of rapid growth spurts. Grimston *et al.* (1993) agreed with these data and suggested that even when interacting variables have been accounted for, differences in BMD occurred mainly as a function of puberty and associated gains in body weight. Thus it has been established that during puberty, the sex difference in bone mass is expressed. Paralleling the studies conducted on adults, recent research has been devoted to the influence of physical activity or participation in sport on the skeletal maturity of children. The results of a limited number of investigations generally indicated significant differences in BMD measures between children matched for gender, race, puberty, and body weight as a function of mechanical loading. Data described in Appendix C also parallels the results found in more mature populations. Sport of higher impacting magnitudes provided a stronger osteogenic effect on BMD and BMC of younger subjects. However, conclusive evidence identified that the most profound effects or accelerated increases in BMD were observed during the periods of rapid growth (Slemenda *et al.*, 1991). Over the past decade, an increased number of children have been participating in competitive sport. Although most authorities agree that such physical pursuits are both beneficial and necessary for normal development, provided that sport be kept in a safe range of impact, the question is, what is a safe range of impact for immature skeletal structures? The fact is often ignored that children are not simply little adults. The immature musculo-skeletal system is less able to cope with repetitive biomechanical stress. Children seem to be physically vulnerable to repeated micro-trauma. They are developmentally unique in that they possess a physis or growth plate in the ends of growing long bones. This proliferating plate of cartilage separates the epiphysis from the metaphysis. The so called "epiphyseal plate closure" signals fusion of primary and secondary centres of ossification and is recognized clinically as bone maturation. However, if injury occurs before epiphyseal plate closure then significant permanent growth disturbance is likely (Gerrard, 1993).

Bonjour *et al.* (1991) commented that although during the period of rapid growth impact or mechanical loading has the greatest effect, this phenomenon may also be responsible for the occurrence of a transient period of relative increase in bone fragility that may account for the pattern of fracture incidence during adolescence. Peak fracture incidence occurs between 12-14 years of age and precedes age at which peak height velocity is attained (Bonjour *et al.*, 1991). It has also been cited that the majority of fractures occur as a result of sport or general physical activities (Gerrard, 1993).

Although work by McCulloch *et al.* (1990) and many others supports the hypotheses that exercise related differences in bone mass confirm the skeleton's potential to respond to the challenge of increased load bearing and bone density established in childhood may be a determinant of adult bone density, the upper limits or potential risks associated are inconclusive. Physical activity in childhood may in fact provide a significant positive contribution to an osteoporosis prevention strategy, however what is the dosage?

Landings

Many sports or sport related activities have an inherent landing component. The task of quantifying the forces of landing and describing the mechanics has been undertaken by several researchers in several sports (Aura & Viitasalo, 1989; Dozzi, 1988; Dufek & Bates, 1990;1991; Nigg, 1985; Ozguven & Berme, 1988; Panzer *et al.*, 1988 ; Schot, Dufek & Bates, 1993; Skelly & Devita, 1990 ; Smith, 1975; Valiant & Cavanagh, 1985). Landing imposes forces on the body that must be absorbed primarily by the musculo-skeletal components of the lower extremities (Dufek & Bates, 1990). If the loads become too great for the body to accommodate, a potential injury situation arises. Therefore, much of the landing related research has been prompted by inquiry into the common occurrence of injuries of the leg and foot, linked to repetitive loading. It has been cited that the majority of injuries are chronic and related to mechanisms in which the foot, ankle, knee, and hip do not properly dissipate repetitive forces. However, it has also been suggested that injurious effects may be associated with or predisposed by specific types of technical or sport related training (Dozzi, 1988; Grimston & Zernicke, 1993).

Although running is not typically classified as a jumping activity, it has been the "forerunner" in landing related research. Running has been defined as a series of small jumps exposing the body to repeated impact forces. Dufek & Bates (1990) reported that impact or passive forces of running range from 1.6 to 3.0 times body weight and predispose many impact related injuries. Although it is recognised by Schot & Dufek

(1991) that the landing technique employed in running is not congruent with jump related landings, impact still predisposes to injury. This leads researchers to the question: if the forces of running predispose injury or trauma, what is the magnitude of the effect of repetitive impact loading in a sport such as gymnastics or figure skating, where tumbling and jumping are the primary components of performance? Preliminary investigations by Lockwood & Gervais (1995) have revealed that impact forces upon landing single, double, and triple revolution jumps in figure skating range between 3 to 9 times the individual's body weight. In a similar impact-type sport, Panzer *et al.* (1988) reported peak vertical impacts experienced by gymnasts executing vaulting skills ranging from 8.8 - 14.4 times the individual's body weight. It is suggested that the long term effects of impact or mechanical loading at these magnitudes warrants further investigations. For a more complete review, recent articles published by Schot & Dufek (1991), and Dufek, Schot & Bates (1993) provide a comprehensive account and evaluation of the research conducted on impact loaded activities, with specific reference to landing in many sporting activities.

A review of the published literature found that a void exists with respect to "landings" in the sport of figure skating. From a scientific standpoint, there have been three significant contributors to our understanding of the mechanics of on-ice jumping, however, none of these have emphasized the landing or impact component. Most of the early work of Aleshinsky (1986; 1988) was descriptive and qualitative in nature. Aleshinsky addressed the gap between biomechanics and its application to coaching techniques in the sport of figure skating. In a comparative analysis of single, double, and triple axel jumps, King *et al.* (1994) focused on the descriptive variables of particular interest to coaches. A three dimensional biomechanical analysis was completed concentrating primarily on the take-off and airborne phases of the jumps executed. Similar to the work of King *et al.* (1994), Miller & Albert (1995) assessed axel performances of Canadian figure skaters to gain further insight into the interactions of major biomechanical factors influencing successful execution and development of computer graphic displays which could assist coaches in understanding the mechanical basis of the performance.

An in depth review of both the scientific and coach based literature published found that the technique, kinetics, and kinematics of landing, as well as the physiological impact on the body have not been investigated.

Biochemical Markers of Bone Turnover

The development of biochemical knowledge of bone has undergone substantial growth in the past decade. Studies of the chemical properties of bone, their regulation of synthesis and secretion, and their interaction with other constituents of bone has provided new insights into the complex mechanisms of bone metabolism. Bone metabolism is characterized by two opposite activities, the formation of new bone by osteoblasts and the degradation (resorption) of old bone by osteoclasts. The rate of formation or degradation of bone matrix can be assessed either by measuring a prominent enzymatic activity of the bone forming cells or by measuring bone matrix components released into circulation during formation or resorption (Delmas, 1993). The majority of biochemical research on bone has been undertaken to investigate the etiology of bone disease, disorders, and age-related alterations in bone metabolism. However, the markers identified in the literature are still of unequal specificity and sensitivity, and some of them have not been thoroughly investigated. At present, mechanisms and markers related to bone formation are becoming elusive however, markers of resorption are less definitive.

In a normal, healthy population, puberty and menopause have acted as a convenient models for evaluation of these measurements. Investigations summarized by Blumsohn *et al.* (1994) explored the interrelationships between pubertal development and biochemical markers of bone turnover in 91 healthy, pubertal girls. Results revealed that bone formation, reflected by osteocalcin and alkaline phosphatase, was maximal in mid puberty and decreased towards adult levels in late puberty. Thus, it was concluded that the rate of bone growth increases dramatically during puberty and is a function of pubertal stage rather than chronological age.

Similar research in adult populations (Epstein *et al.*, 1986) investigated the effect of age on serum levels of biochemical bone indices. In males, vitamin D remained essentially constant with increasing age up to 65 years, then decreased significantly. In females vitamin D increased up to 65 years of age, then decreases significantly. Serum PTH in males increases with advancing age with the rate of increase greater after 65 years. However, in females a significant increase in PTH did not occur until after 65 years of age.

A limited number of studies in animals and humans have examined the effects of physical activity on the biochemistry of bone (Price *et al.*, 1995; Lueken *et al.*, 1993). It has been proposed that the mechanisms for loading and unloading - related regulation of bone cell behaviour may be studied in vitro by investigating the biochemical changes. With the use of radio immune assays, it is now possible to supplement such measures of bone structure with biochemical measurements of bone metabolism. As cited earlier in this review, Price *et al.* (1995) claimed that measurements of biochemical markers of bone metabolism have the potential for monitoring and optimizing exercise regimens designed to induce adaptive responses in skeletons of horses.

Lueken *et al.* (1993) examined the acute effects of immobilization on human skeletons to further understand the mechanism of bone loss in physical unloading. The sequence of changes in indices of circulation markers of bone formation and bone resorption in both serum and urine indicated that osteocalcin increases were the earliest response of bone to inactivity and were proposed as a response to an increase in bone resorption. These results disclosed evidence that bone resorption peaked as early as four days after immobilization.

It has been suggested as a result of the work on both animals and humans that the development of assays for the products of bone cells that mediate the processes of bone formation and resorption can now provide a means to assess more specifically the overall skeletal responses to activity and inactivity, disease, and the effect of treatment (Akesson, 1995). Normative ranges of serum assays of biochemical indices of bone formation and resorption as reported by the literature are outlined in Appendix D. Although it has been indicated that serum assays developed to assess bone formation are of value in diagnosis management and treatment of bone disease and disorder, each assay also has certain limitations that must be considered.

For the purpose of the present investigation, the following six biochemical markers of bone turnover have been reviewed: osteocalcin (OS or GLA or BGP), parathyroid hormone (PTH), 25-hydroxy vitamin D (25-(OH)D), Carboxy terminal propetide of type I collagen (PICP), carboxy terminal telopeptide of type I collagen (ICTP), and calcium.

Table 2.1 Biochemical Markers of Bone Turnover

Markers	Abbreviations
Osteocalcin	OS; GLA; BGP
Parathyroid Hormone	PTH
25 Hydroxy Vitamin D	25-OH-D
Carboxy Terminal Propeptide of Type I CollagenCarboxy	PICP
Terminal Telopeptide of Type I Collagen	ICTP
Calcium	Ca

Parathyroid Hormone (PTH): Parathyroid hormone (PTH) is one of three calcium regulating hormones, the others being osteocalcin and vitamin D. It is produced exclusively by the parathyroid glands. The primary function of PTH is to elicit the adaptive changes that serve to maintain a constant concentration of calcium in the extra cellular fluid. The catabolic effect of PTH on bone appears to be the net result of stimulation of osteoclast bone resorbing activities and an accompanying inhibition of osteoblast bone forming activities (Peck, 1986). As the concentration of blood calcium falls, the parathyroids synthesize and release increased amounts of PTH. PTH promotes the mobilization of calcium by stimulating osteoclast activity and calcium resorption. Prolonged elevated levels of PTH will also increase osteoblast activity, influencing the rate of bone turnover and remodelling. Studies investigating the relationships between PTH, age and gender have indicated an increase in PTH with advancing age in both males and females (Minisola *et al.*, 1993).

Osteocalcin (OS, BGP or GLA): Osteocalcin is a non collagenous protein of bone matrix and is only known to be synthesized by the bone forming cells, the osteoblasts. It has a molecular weight of 5800 Daltons and is composed of 49 amino acids (Kruse & Kracht, 1986). In addition to its presence in bone matrix, Os circulates in blood where it can be measured by radio immuno assays. Blood levels of Os have been prostulated to reflect the rate of bone turnover and more specifically the bone formation rate (Delmas *et al.*, 1990). Pediatric studies have indicated that serum Os in healthy children is higher in individuals younger than 15 years than in adults. (Kruse & Kracht, 1986). It has therefore been scientifically recognized as a specific bone formation marker with increased levels found during rapid growth spurts and in bone diseases characterized by increased bone turnover.

Production of this hormone is stimulated by elevated levels of 25-hydroxy vitamin D. In vitro studies have demonstrated that Os strongly inhibits precipitation of calcium and phosphate, suggesting that this bone protein may prevent excessive mineralization (Garnero et al., 1994). Studies conducted by Benucci *et al.* (1993) have indicated that Os also parallels increases in both 25-hydroxy vitamin D and PTH reconfirming that measurements of Os are a reliable index of bone turnover, providing that both vitamin D and PTH are within normal ranges. Delmas (1993) states that in most cases Os is a valid marker of bone turnover when resorption and formation are coupled and is a specific marker of formation whenever formation and resorption are uncoupled.

25 Hydroxy Vitamin D (25-OH-D): 25-OH-D is the most widely evaluated assay to determine vitamin D status and has a potential role in evaluating calcium and bone metabolism disorders in humans (Benucci et al., 1993). Its production is regulated by the amount of ultraviolet light in solar and sky radiation as well as duration of exposure and therefore is predisposed to significant seasonal variation. In addition to parallelling fluctuations in PTH, 25-OH-D stimulates osteoblast activity to increase production of Os.

Carboxy Terminal Propeptide of Type I Collagen (PICP): PICP has a non collagenous structure. PICP reflects matrix formation directly and is independent of subsequent mineralization (Charles *et al.*, 1994). Increased levels of PICP are seen in a number of conditions involving somatic growth or an enhanced metabolic rate of bones. Thus the PICP assay may be useful in three research areas: 1) growth disorders in children, 2) rapid bone loss states after menopause and during treatment by estrogens or other drugs that slow down bone metabolic rate, and 3) local measurements of the rate of type I collagen synthesis in wound fluid, cerebrospinal fluid, bronchoalveolar lavage fluid and other body fluids. Studies have confirmed that PICP may be an accurate biochemical marker to predict and evaluate growth velocity in children (Trivedi *et al.*, 1991). It may therefore be useful in identifying the individual at risk and monitoring the efficacy of treatment.

Carboxy Terminal Telopeptide of Type I Collagen (ICTP): ICTP is crosslinked through pyridinoline and is liberated into serum during type I collagen degradation. Studies have supported the use of ICTP levels to reflect rates of bone resorption in patients with metabolic bone disease measured histomorphometrically or by calcium kinetic studies (Mora *et al.*, 1986). Markers of resorption have been shown to peak in the first year of life and in mid puberty then decrease toward adult life.

Calcium (Ca): Calcium is known to be a threshold nutrient. Below a certain critical value (the threshold) calcium availablity limits bone accumulation. However above that threshold, additional increases in calcium intake have no effect on bone mass. The role of calcium in bone metabolism and maintenance has been studied using epidemiological, bone mass measurement methods and metabolic balance studies. It is known that calcium is essential for bone health, however its role in maintenance of bone mass in the young skeleton is controversial. It is often stated that an adequate intake of calcium is required but the question remains as to what is considered adequate.

Bone Assessment Techniques & Data Interpretation

Bone densitometry has undergone rapid changes over the last decade with dual energy X-ray absorptiometry (DEXA) virtually supplanting its predecessors because of markedly improved resolution, reproducibility, decreased scan time, and radiation exposure (Fuleihan *et al.*, 1995). In light of these technological advances, DEXA has become a standard method in assessing bone mineral density (BMD) and bone mineral content (BMC) (Appendix K).

DEXA consists of a flat bed, a self contained x-ray source mounted beneath the table and x-ray detector mounted on a movable arm above the table. An A/D converter digitizes the information and sends it to an interfaced computer for analysis. The underlying principle of this technique is based upon the absorption of ionising radiation by bone - the amount of radiation attenuation is directly related to the amount of bone present. DEXA uses x-rays of two different energy levels; this dual energy scheme allows soft tissue within the selected area to be subtracted out, leaving only bone to be imaged and estimated. Bone mineral content (BMC - grams of calcium hydroxy apatite) is the primary parameter quantified (Sievanen *et al.*, 1996). To give this calculated number a physical meaning requires standardization of the thickness of the slice, usually done by expressing the amount of bone in the cross section as if measured in a slice 1 cm thick. Bone mineral density (BMD - g/cm^2) is calculated by dividing the total bone mineral in grams (BMC) by the projected area of the specified region. Therefore, this technique determines BMD from an anterior-posterior image, ie., in two dimensions. In light of the two dimensional limitation, it has been suggested that BMD seems to be the most appropriate parameter taking into account both BMC and average bone width within a given projection and thus providing two dimensional macroscopic information on bone geometry (Sievanen *et al.*, 1996).

However the interpretation of BMD values is not without controversy, specifically if the researcher is examining changes in BMD. Studies conducted by Carter *et al.* (1992) have demonstrated that measures of BMD and BMC can be misleading when used to compare bones of different sizes due to inherent biases caused by differences in bone thickness. Therefore, Carter's group have described a new method of analysis to reduce the confounding effect of bone size and better reflect the bone apparent density (BMAD - grams of calcium hydroxy apatite/cm^3). BMAD has been recommended as an alternative parameter to examine changes over time concurrent with growth and the associations between bone and various size dependent non bone measures (ie., muscle strength, calcium intake) (Sievanen *et al.*, 1996).

The enhanced precision of DEXA has allowed for the detection of very small changes in BMC and BMD (Sievanen *et al.*, 1996). Studies conducted on the reproducibility of DXA have been performed by several researchers (Dequeker *et al.*, 1995; Fuleihan *et al.*, 1995). The results of these studies have provided a basis for designing protocols for multi-centre studies using currently installed densitometers. These studies succeeded in showing that Hologic, Lunar, and Norland brandname machines gave similar results, after their results were standardized with regard to the variables assessed.

Individual Inventories

A. Maturational Assessment: Assessment of maturational age is imperative in studies which investigate the effects of physical activity on performance and physiological functions. The most common methods used in estimating biological age include estimating skeletal age from hand-wrist x-rays and the assessment of secondary sex characteristics. Because of concerns related to radiation exposure and adolescent privacy, ethics committees are becoming increasingly reticent in approving procedures for research investigations. In order to address these concerns, maturity rating assessments have been developed based on other parameters such as: height velocity, pubic hair self-assessment, menarche (girls), axillary and facial hair (boys) and chronological age. Although the limitations introduced when attempting to predict hormonal maturity from self-assessments must be recognised, these systems have high inter- and intra- tester reliability, are simple to use, and respect the privacy of subjects. Faulkner *et al.* (1995) have found these inventories to be readily accepted by ethics committees, school boards, parents and children and thus recommend it as research tool.

B. Calcium Food Frequency Inventory: Food frequency questionnaires have been developed and validated to assess an individual's usual dietary intake. These questionnaires contain a list of foods selected to account for intake of specified nutrients in an identified population. Subjects are asked to indicate their frequency of consumption for each item over a relevant period of time in the recent or more distant past. These questionnaires are designed primarily to measure relative levels of food and nutrient intakes and are therefore most useful in research analyses of the relationship between diet and risk of disease (Feskanich & Willett, 1993). Food frequency questionnaires are most appropriate when average long-term diet is of interest but are not effective in achieving a precise measurement of short-term consumption. They are excellent for ranking intake of particular foods or food groups. Ease of administration and processing make this a feasible method of dietary assessment.

C. *Physical Activity Questionnaire*: Physical activity is defined as, "any bodily movement produced by skeletal muscles that results in energy expenditure" (Shelton & Klesges, 1995). It can be characterized by work, sports, leisure, or minute muscular activities. Assessment of physical activity has become increasingly important with the growing awareness of the association of physical activity, health, growth, and development (Bailey *et al.*, 1994). There have been many attempts at quantifying duration, intensity, and frequency of activity via self administered recall questionnaires, interview administered recall, diaries, motion sensors, heart rate monitors, and direct observations. Yet many problems and inconsistencies persist in the accurate characterization and quantification of activity in non laboratory settings under natural conditions.

Despite several major limitations of questionnaires as a common assessment technique, there are distinct advantages over other methods being used. A questionnaire focuses on the ability to classify one's level of activity and/or recall activities over various periods of time. Shelton & Klesges (1995) report that in studying large groups of individuals, the questionnaire method is the only viable instrument of choice. However, differences exist in method of administration, time frame over which the activity is assessed, type of activity assessed and the measurement scale used.

Conclusions & Future Directions

The acquisition and maintenance of the skeletal structures are influenced by several factors, including genetics, hormones, maturation, nutrition, the environment, and mechanical loading. The importance of physical stress and weight bearing exercises in bone modelling and remodelling and consequently in maintaining bone mineralization is generally accepted. Although the data does not permit any exact evaluation of optimal load for attaining peak bone mass, it is concluded that physical activity provides a powerful osteogenic stimulus in the populations reviewed.

As seen in the research designs of both adult and children studies, quantification of specific loads experienced during physical activity and sporting events were not conducted. As stated previously, the technology allowing quantification of external mechanical forces experienced during sport performance is somewhat limited. Furthermore, calculating the internal effect on skeletal structure based upon external data is even more sceptical. Therefore, an analysis of a dose-response relationship has not been thoroughly examined or established from the existing data.

To assess the complexity of this issue more completely, an integrated approach to research should be conducted. Biomechanical, biochemical, and physiological aspects of the responses of bone to mechanical loading should be investigated. Currently, evidence supporting the effect of the type, intensity, and duration of exercise necessary to influence bone mineral density in humans is inconclusive. Potential risks of the factors identified remain to be determined. Delmas (1993) suggested that the combination of bone mass measurements and assessment of bone turnover by a battery of specific markers can predict risk, detect abnormalities in bone turnover and furthermore, monitor an intervention. This would allow for a better understanding of normal growth and development and possibly the ability to predict the influence of other confounding and interacting factors could be better determined.

References

Akesson, K. (1995). Biochemical markers of bone turnover - A review. Acta *Orthop Scand.*, 66(4): 376-386.

Aleshinsky, S. (1986). What biomechanics can do for figure skating. *Skating*, November; 10-15.

Aleshinsky, S. (1988). Strength and conditioning program for figure skating. *NSCA Journal*, 10(4): 26-30.

Aloia, J. (1989). Osteoporosis. A guide to prevention and treatment. Champaign, IL: Leisure Press.

Aura, O. & Viitasalo, J. (1989). Biomechanical characteristics of jumping. *International Journal of Sport Biomechanics*, 5: 89-98.

Bailey, D. (1994). Invited Paper: Physical activity and the attainment of peak bone mass in children. *The Australian Journal of Science and Medicine in Sport*, 26(½):3-5.

Bailey, D. & McCulloch, R. (1990). Bone tissue and physical activity. *Canadian Journal of Sport Sciences*, 15(4): 229-239.

Bailey, R., Olson, J., Pepper, S., Porszazs, J., Barstow, T. & Cooper, D. (1994). The level and tempo of children's physical activities: an observational study. *Medicine and Science in Sports and Exercise*, 27(7): 1033-1041.

Bassey, E. & Ramsdale, S. (1994). Increase in femoral bone density in young women following high-impact exercise. Osteoporosis *International*, 4: 72-75.

Benucci, A., Tommasi, M., Fantappie, B., Scardigli, S., Ottanelli, S., Pratesi, E. & Romano, S. (1993). Serum 24-hydroxyvitamin D levels in normal subjects: seasonal variations and relationships with parathyroid hormone and osteocalcin. *Journal Nuclear Biology and Medicine*, 37(2): 77-82.

Blumsohn, a., Hannon, R., Wrate, R., Barton, J., Al-Dehaimi, A., Colwell, A. & Eastell, A. (1994). Biochemical markers of bone turnover in girls during puberty. *Clinical Endocrinology*, 40: 663-670.

Bonjour, J., Theintz, G., Buch, B., Slosman, D. & Rizzoli, R. (1991). Critical years and stages of puberty for spinal and femoral bone mass accumulation during adolescence. *Journal of Clinical Endocrinology and Metabolism*, 73(3): 555-563.

Burger, E. & Veldhuijzen, J. (1993). Influence of mechanical factors on bone formation, resorption and growth in vitro. In Brian K. Hall (ed.), Bone, 7: Bone Growth-B, CRC Press, London: 37-53.

Carter, D., Bouxsein, M. & Marcus, R. (1992). New approaches for interpreting projected bone densitometry data. *Journal of Bone and Mineral Research*, 7(2): 137-145.

Charles, P., Mosekilde, L., Risteli, L., Risteli, J. & Eriksen, E. (1994). Assessment of bone remodelling using biochemical indicators of type I collagen synthesis and degradation: relation to calcium kinetics. Bone and Mineral, 24: 81-94.

Chilibeck, P., Sale, D. & Webber, C. (1995). Exercise and bone mineral density. *Sport Medicine*, 19(2): 103-122

Cooper, C., Cawley, M., Bhalla, A., Egger, P., Ring, F., Morton, L. & Barker, D. (1995). Childhood growth, physical activity and peak bone mass in women. *Journal of Bone and Mineral Research*, 10(6): 940-947.

Delmas, P. (1993). Biochemical markers of bone turnover. *Journal of Bone and Mineral Research*, 8(2): S549-S555.

Delmas, P., Price, P. & Mann, K. (1990). Validation of bone gla protein (osteocalcin) assay. *Journal of Bone and Mineral Research*, 5(1): 3-4.

Delmas, P., Christiansen, C., Mann, K. & Price, P. (1990). Bone Gla protein (osteocalcin) assay standardization report. *Journal of Bone and Mineral Research*, 5(1): 5-11.

Dequeker, J., Pearson, J., Reeve, J., Henley, M., Bright, J., Felsenberg, D., Kalender, W., Laval- Jeantet, A-M., Ruegsegger, P., Adams, J., Diaaz Curiel, M., Fischer, M., Galan, F., Geusens, P., Hyldstrup, L., Jaeger, P., Kotzki, P., Droger, H., Lips, P., Mitchell, A., Louis, O. Perez Cano, R., Pols, H., Reid, D., Ribot, C., Schneider, P. & Lunt, M. (1995). Dual X-ray absorptiometry - Cross calibration and normative reference ranges for the spine: Results of a European community concerted action. *Bone*, 17(3): 247-254.

Dozzi, P. (1988). Impact forces and deceleration during ballet jumps under different conditions. Proceeding from the Fifth Biennial Conference and Symposium, Canadian Society for Biomechanics, Aug.: 58-59.

Dufek, J.S. & Bates, B.T. (1990). The evaluation and prediction of impact forces during landings. *Medicine and Science in Sports and Exercise*, 22(2): 370-377.

Dufek, J.S. & Bates, B.T. (1991). Biomechanical factors associated with injury during landing in jump sports. *Sports Medicine*, 12(5): 326-337.

Epstein, S., Bryce, G., Hinman, J., Miller, O., Riggs, B., Jui, S. & Johnston, C. (1986). The influence of age on bone mineral regulating hormones. Bone, 7, 421-425.

Faulkner, R., Bailey, D., Drinkwater, D., Wilkinson, A., Houston, C. & McKay, H. (1993). Regional and total body bone mineral content, bone mineral density and total body tissue composition in children 8-16 years of age. *Calcified Tissue* International, 53: 7-12.

Faulkner, R., Bailey, D., McKay, H. & Drinkwater, D. (1995). A non-invasive method for determining maturational status in children and adolescents in longitudinal studies. *Personal Communication*, University of Saskatchewan, Saskatoon, Saskatchewan.

Fehling, P., Alekel, L., Clasey, J., Rector, A. & Stillman, R. (1995). A comparison of bone mineral densities among female athletes in impact loading and active loading sports. *Bone*, 17(3): 205-210.

Feskanich, M. & Willet, W. (1993). The use and validity of food frequency questionnaires in epidemiologic research and clinical practice. *Medicine, Exercise, Nutrition and Health*, 2: 143-154.

Fonseca, V., D'Souza, V., Houlder, S., Thomas, M., Wakeling, A. & Dandona, P. (1988). Vitamin D deficiency and low osteocalcin concentrations in anorexia nervosa. *Journal of Clinical Pathology*, 41: 195-197.

Forwood, M. & Burr, D. (1993). Physical activity and bone mass: exercises in futility? *Bone and Mineral*, 21: 89-112.

Friedlander, A., Genant, H., Sadowsky, S. Byl, N. & Gluer, C. (1995). A two year program of aerobics and weight training enhances bone mineral density of young women. *Journal of Bone and Mineral Research*, 10(4): 574-585.

Frost, H. (1973). Bone Modelling and Skeletal Modelling Errors. Charles C. Thomas Publishing, Illinois.

Fuleihan, G., Testa, M., Angell, J., Porrino, N., Leboff, M. (1995). Reproducibility of DXA Absorptiometry: A model for bone loss estimates. *Journal of Bone & Mineral Research*, 10(7): 1004-1014.

Garnero, P., Grimaux, M., Seuin, P. & Delmas, P. (1994). Characterization of immunoreactive forms of human osteocalcin generated in vivo and in vitro. *Journal of Bone and Mineral Research*, 9(2): 255-264

Gerrard, D. (1993). Overuse injury and growing bones: the young athlete at risk. *British Journal of Sport Medicine*, 27(1).

Glastre, C., Bralillon, P., David, L., Cochat, P., Meunier, P. & Delmas, P. (1990). Measurement of bone mineral content of the lumbar spine by dual energy x-ray absorptiometry in normal children: Correlations with growth parameters. *Journal of Clinical Endocrinology and Metabolism*, 70: 1330-1333.

Graham, M. (1989). The use of serum levels of procollagen propeptides to predict growth velocity. *Journal of Pediatrics*, Gastroenterology and Nutrition, 8: 143.

Grimston, D., Engsberg, J., Kloiber, R. & Hanley, D. (1991). Bone mass, external loads and stress fracture in female runners. *International Journal of Sport Biomechanics*, 7: 293-302.

Grimston, S., Morrison, K., Harder, J. & Hanley, D. (1992). Bone mineral density during puberty in Western Canadian children. *Bone & Mineral*, 19: 85-96.

Grimston, S., Willows, N. & Hanley, D. (1993). Mechanical loading regime and its relationship to bone mineral density in children. *Medicine & Science in Sports & Exercise*, 25(11): 1203-10.

Grimston, S. & Zernicke, R. (1993). Exercise-related stress responses in bone. *Journal of Applied Biomechanics*, 9: 2-14.

Heinonen, A., Oha, P., Kannus, P., Sievanen, H., Haapasalo, H., Manttari, A. & Vuori, I. (1995). Bone mineral density in female athletes representing sports with different loading characteristics of the skeleton. *Bone*, 17(3): 197-203.

Heinonen, A., Oja, P., Kannus, P., Sievanen, H., Manttari, A. & Vuori, I. (1993). Bone mineral density of female athletes in different sports. *Bone & Mineral*, 2: 1-14.

Hert, J., Liskova, M., & Landa, J. (1971). Reaction of bone to mechanical stimuli. Part I: Continuous and intermittent loading of tibia in rabbit. *Folia Morph.* (Praha), 19: 290.

Kannus, P., Sievanen, H., Oja, P. & Vuori, I. (1994). The site specific effects of long-term unilateral activity on bone mineral density and content. *Bone*, 15(3): 279-284.

Katzman, D., Bachrach, L., Carter, D. & Marcus, R. (1991). Clinical and anthropometric correlates of bone mineral acquisition in healthy adolescent girls. *Journal of Clinical Endocrinology and Metabolism*, 73(6): 1332-1339.

King, D., Arnold, A. & Smith, S. (1994). A kinematic comparison of single, double, and triple axels. *Journal of Applied Biomechanics*, 10: 51-60.

Kirchner, E., Lewis, R. & O'Connor, P. (1995). Bone mineral density and dietary intake of female college gymnasts. *Medicine & Science in Sports and Exercise*, 27: 496-502.

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

Kruse, K. & Kracht, U. (1986). Evaluation of serum osteocalcin as an index of altered bone metabolism. *European Journal of Pediatrics*, 145: 27-33.

Lanyon, L. (1993). Biomechanical properties of bone and response of bone to mechanical stimuli: Functional strain as a controlling influence on bone modelling and remodelling behaviour. In Hall, B. (ed.), Bone, Volume 3: Bone Matrix and Bone Specific Products. CRC Press, London: 80-108.

Lanyon, L. & Rubin, C. (1984). Static vs. dynamic loads as an influence on bone remodelling. *Journal of Biomechanics*, 17: 897-905.

Leuken, S., Arnaus, S., Taylor, A. & Baylink, D. (1993). Changes in markers of bone formation and resorption in a bed rest model of weightlessness. *Journal of Bone and Mineral Research*, 8(12): 1433-1438.

LeVeau, B. & Bernhardt, D. (1984). Developmental Biomechanics: Effects of forces on the growth, development, and maintenance of the human body. *Physical Therapy*, 64(12): 874-1882.

Lockwood, K. & Gervais, P. (1995). Quantification of impact forces upon landing single, double, and triple revolution jumps in figure skaters. Conference Proceedings of the International Society of Biomechanics (ISB), (pp. 566-567), Jyvaskyla, Finland.

Lohman, T., Going, S., Pamenter, R., Hall, M., Boyden, T., Houtkooper, L., Ritenbaugh, C., Bare, L., Hill, A. & Aicin, M. (1995). Effects of resistance training on regional and total bone mineral density in premenopausal women: A randomized prospective study. *Journal of Bone and Mineral Research*, 19(7): 1025-1024.

Margulies, J., Simkin, A., Leichter, I., Bivas, A., Steinberg, R., Giladi, M., Stein, M., Kashtan, H. & Milgrom, C. (1986). Effect of intense physical activity on the bone-mineral content in the lower limbs of young adults. *Journal of Bone and Joint Surgery*, 68A(7): 1090-1093.

Martin, A. & McCulloch, R. (1987). Bone dynamics: stress, strain and fracture. *Journal of Sport Sciences*, 5: 155-163.

McCulloch, R., Bailey, D., Houston, C. & Dodd, B. (1990). Effects of physical activity, dietary calcium intake and selected lifestyle factors on bone density in young women. *Canadian Medical Association Journal*, 142(3): 221-227.

McCulloch, R., Bailey, D., Whalen, R., Houston, C., Faulkner, R. & Craven, B. (1992). Bone density and bone mineral content of adolescent soccer athletes and competitive swimmers. Pediatric *Exercise Science*, 4: 319-330.

McKay, H., Bailey, D., Wilknson, A. & Houston, C. (1994). Familial comparison of bone mineral density at the proximal femur and lumbar spine. *Bone and Mineral*, 24: 95-107.

Miller, D. & Albert, W. (1995). Assessing axel performance of Canadian figure skaters. Report submitted to Sport Canada.

Minisola, S., Pacitti, M., Scarda, A., Posso, R., Romagnoli, E., Carnevale, V., Scarnecchia, L. & Mazzuoli, F. (1993). Serum ionized calcium, parathyroid hormone and related variables: effect of age and sex. *Bone and Mineral*, 23: 183-193.

Nichols, D., Sanborn, C., Bonnick, S., Ben-Ezra, V., Gench, B. & DiMarco, N. (1994). The effects of gymnastics training on bone mineral density. *Medicine and Science in Sports and Exercise*, 26(10): 1220-1225.

Mora, S., Cella, D., Puzzovio, M., Cairella, R. & Chiumello G. (1993). Radio immunoassay for a new bone resorption marker and results for pediatric subjects. *Clinical Chemistry*, 39(8): 1745-1747.

Nigg, B.M. (1985). Loads in selected sport activities - An overview. In Winters, D.A. & Norman, R.W. (eds.) *Biomechanics IX-B*, Human Kinetic Publishers, Champaign, Il., 91-96.

Nilsson, B. & Westlin, N., (1971). Bone density in athletes. *Clinical Orthopaedics and Related Research*, 77:180-182.

Orwoll, E., Oviatt, S. & Nafarelin/Bone Study Group. (1991). Longitudinal precision of dual-energy X-ray absorptiometry in a multicenter study. *Journal of Bone and Mineral*, 6(2): 191-197.

Ott, S. (1991). Bone density in Adolescents. *The New England Journal of Medicine*, 325(23): 1646-1647.

Ozguven, H. & Berme, N. (1988). An experimental and analytical study of impact forces during human jumping. *Journal of Biomechanics*, 21(12): 1061-1066.

Panzer, W., Wood, G., Bates, B. & Mason, B. (1988). Lower extremity loads in landings of elite gymnasts. *International Series on Biomechanics, Biomechanics XI-B*: 727-735.

Peck, W. (1983). Bone and Mineral Research/1: A yearly survey of developments in the field of bone and mineral metabolism. Elsevier Science Publishers, Amsterdam: 157-187.

Peck, W. (1985). Bone and Mineral Research/3: A yearly survey of developments in the field of bone and mineral metabolism. Elsevier Science Publishers, Amsterdam: 259-293.

Peck, W. (1986). Bone and Mineral Research/4: A yearly survey of developments in the field of bone and mineral metabolism. Elsevier Science Publishers, Amsterdam: 103-129.

Pirnay, F., Bodeux, M., Crielaard, J. & Franchimont, P. (1987). Bone mineral content and physical activity. *International Journal of Sports Medicine*, 8: 331-335.

Price, J., Jackson, B., Eastell, R., Wilson, A., Russel, R., Lanyon, L. & Goodship, A. (1995). The response of the skeleton to physical training: A biochemical study in horses. *Bone*, 17(3): 221-227.

Ruiz, J., Mandel, C. & Garabedian, M. (1995). Influence of spontaneous calcium intake and physical exercise on the vertebral and femoral bone mineral density of children and adolescents. *Journal of Bone and Mineral Research*, 10(5): 675-682.

Robinson, T., Snow-Harter, C., Taaffe, D., Gillis, D., Shaw, J. & Marcus, R. (1995). Gymnasts exhibit higher bone mass than runners despite similar prevalence of amenorrhea and oligomenorrhea. *Journal of Bone and Mineral Research*, 10(1): 26-35.

Schot, P., Dufek, J. & Bates, B. (1993). Landing performance, Part II: Assessment and future directions. *Medicine, Exercise, Nutrition and Health*, 2: 135-142.

Schot, P. & Dufek, J. (1991). Landing performance, Part I: Kinematic, kinetic and neuromuscular aspects. *Medicine, Exercise, Nutrition and Health*, 2: 69-83.

Seibel, M., Cosman, F., Shen, V., Gordon, S., Dempster, D., Ratcliffe, A. & Lindsay, R. (1993). Urinary hydroxygpyridinium crosslinks of collagen as markers of bone resorption and estrogen efficacy in postmenopausal osteoporosis. *Journal of Bone and Mineral Research*, 8(7): 881- 889.

Shelton & Klesges (1995). Measures of physical activity and exercise. In D.B. Allison Ed., Handbook of assessment methods for eating behaviours and weight related problems: measures, theories, and research. Sage Publishing, London.

Sievanen, H., Kannus, Nieminen, V., Heinonen, A., Oja, P. & Vuori, I. (1996). Estimation of various mechanical characteristics of human bones using dual energy x-ray absorptiometry: methodology and precision. *Bone*, 18(1): 17S-27S.

Sievanen, H., Kannus, P., Heinonen, A., Oja, P. & Vuori, I. (1994). Bone mineral density and muscle strength of lower extremities after long-term strength, subsequent knee ligament injury and rehabilitation: A unique 2-year follow-up of a 26-year-old female student. *Bone*, 15(1): 85-90.

Slemenda, D., Reister, T., Hui, S., Miller, J., Cristian, J. & Johnston, C. (1994). Influences on skeletal mineralization in children and adolescents: Evidence for varying effects of sexual maturation and physical activity. *Journal of Pediatrics*, 125: 201-207.

Slemenda, C. & Johnston, C. (1993). High intensity activities in young women: site specific bone mass effects among female figure skaters. *Bone and Mineral*, 20: 125-132.

Slemenda, C., Millar, J., Hui, S., Reister, T. & Johnston, C. (1991). Role of physical activity in the development of skeletal mass in children. *Journal of Bone and Mineral Research*, 6(11): 1227-1233.

Skelly, W. & Devita, P. (1990). Compressive and shear forces on the tibia and knee during landing. Proceedings of the VIth Biennial Conference and Human Locomotion Symposium of the Canadian Society of Biomechanics, Quebec: 59-60.

Snow-Harter, C., Bouxsein, M., Lewis, B., Charette, S., Weinstein, P. & Marcus, R. (1990). Muscle strength as a predictor of bone mineral density in young women. *Journal of Bone and Mineral Research*, 5(6): 589-595.

Smith, A.J. (1975). Estimates of muscle and joint forces at the knee and ankle during a jumping activity. *Journal of Human Movement Studies*, 1: 78-86.

Smith, E. & Gilligan, C. (1991). Physical activity effects on bone metabolism. *Calcification Tissue International*, (Suppl.) 49: S50-S54.

Southard, R., Morris, J., Mahan, J., Hayes, J., Torch, M., Sommer, A. & Zipf, W. (1991). Bone mass in healthy children: Measurement with quantitative DXA. *Radiology*, 179: 735-738.

Suominen, H. (1993). Bone mineral density and long term exercise: An overview of cross-sectional athlete studies. *Sports Medicine*, 16(5): 316-330.

Trivedi, P., Risteli, J., Risteli, L., Hindmarsh, P., Brook, C. & Mowat, A. (1991). Serum concentrations of the type I and III procollagen propetides as biochemical markers of growth velocity in healthy infants and children and in children with growth disorders. *Pediatric Research*, 30: 276-280.

Valiant, G.A. & Cavanagh, P.R. (1985). A study of landing from a jump: Implications for the design of a basketball shoe. In Winter, D., Norman, R., Wells, R., Hayes, K. & Patla, A. (ed.), Biomechanics IX-B. Champaign: Human Kinetics: 117-122.

Wahner, H. (1987). Measurement of bone mineral by photon absorptiometry. In Ignac Fogelman (ed.), Bone Scanning in Clinical Practice, Springer-Verlag, London: 249-256.

Wolff, J. (1892). The Law of Bone Transformation. A. Hirshwald, Berlin.

Wolman, R., Faulman, L., Clark, P., Hesp, R. & Harries, M. (1991). Different training patterns and bone mineral density of the femoral shaft in elite, female athletes. Annals *of the Rheumatic Diseases*, 50: 487-489.

Young, D., Hopper, J., Nowson, C., Green, R., Sherwin, A., Kaymakci, B., Smid, M., Guest, C., Larkins, R. & Wark, J. (1995). Determinants of bone mass in 10-26 year old females: a twin study. *Journal of Bone and Mineral Research*, 10(4), 558-567.

Zanchetta, J., Plotkin, H. & Alvarez Filgueira, M. (1995). Bone mass in children: Normative values for the 2-20 year old population. *Bone*, 16(4) Sup: 393S-399S.

CHAPTER THREE

Biomechanics of Landing On-Ice Jumps in Figure Skating

Project I

IMPACT FORCES UPON LANDING SINGLE, DOUBLE, AND TRIPLE REVOLUTION JUMPS IN FIGURE SKATERS

Presented at International Society of Biomechanics
Jyvaskyla, Finland
July, 1995

Presented at the 1996 EMED User's Scientific Conference
Penn State, USA
August, 1996
Abstract submitted for publication in the Journal of Clinical Biomechanics

Full Manuscript submitted for Publication to the Journal of Applied Biomechanics
September, 1996

Project II

KINEMATIC CHARACTERISTICS OF IMPACT ABSORPTION UPON LANDING MULTI-REVOLUTION JUMPS IN FIGURE SKATING

Presented at the International Society of Biomechanics in Sport
Thunder Bay, Canada
August, 1995

IMPACT FORCES UPON LANDING SINGLE, DOUBLE, AND TRIPLE REVOLUTION JUMPS IN FIGURE SKATERS

Abstract

On-ice training regimes employed by competitive figure skaters of all ages are characterized by repetitive impact or mechanical load-type activities. A comparison of vertical impact forces obtained upon landing single, double, and triple revolution jumps was conducted to investigate the potential risks that may be imposed on young athletes participating in this type of training and performance. Mean impact forces (%BW) measured upon landing increased with additional revolutions. Furthermore, an inverse relationship between relative impact force (%BW) and time differences (ms) between the fore and rear foot peak force contacts was revealed. The landings of multi-revolution jumps not only displayed significantly higher force values, the peak impact force was also distributed over a smaller area and over a shorter period of time in comparison to the single revolution jumps.

Relevance

Competitive success in the sport of figure skating has been largely attributed to the skater's ability to execute multi-revolution jumps, landing backwards, on a single leg, in a prescribed configuration. The extent to which additional revolutions contributed to greater vertical force upon impact was assessed to determine if advanced technical feats placed these young athletes at risk of potential impact related injuries.

Key Words: Figure Skating; Landings; Impact Force; Revolution.

Introduction

On-ice jumping has been identified as the most progressive element of a figure skater's performance. As a result, athletes of younger ages and developmental stages are attempting to perform more physically advanced technical feats such as the execution and landing of single, double, triple, and potentially quadruple revolution jumps. A primary concern arising as a consequence of the intensive nature of jump training is the potential for impact related injuries. Although some research suggests that musculo-skeletal stress, such as enhanced physical activity during the growth years, may stimulate bone growth and development, there is increasing evidence that intense impact loading may have a negative influence on bone health (Forwood & Burr, 1993). This aspect of research has not been investigated in the sport of figure skating. However, a number of authors (Dufek & Bates, 1991; McNitt-Gray, 1991; Panzer, Wood, Bates & Mason, 1988) in similar impact related sports with an inherent landing component, have suggested that landings account for the highest incidence of injury to the lower extremities and warrants further investigation. It should be noted that in the sport of figure skating, landings are consistently executed on the same leg.

Previous investigations conducted on both animal (Radin, Parker, Pugh, Steinberg, Paul & Rose, 1973) and humans (Robbins & Gouw, 1990) have also associated this impact-type loading with injury and specifically, the degeneration of tissue structures of the body. The question of whether the landing impact increases with advanced jumping techniques such as additional revolution and whether the musculo-skeletal systems of young athletes are sufficiently mature or strong enough to endure the stresses of today's training demands must be addressed. Thus, the purpose of this research was to compare and contrast the vertical impact forces upon landing single, double, and triple revolution jumps in on-ice jumping. It was hypothesized that the landings of multi-revolution jumps would have greater impact forces (%BW) compared to single revolution jumps.

Methods and Procedures

Subjects

Fourteen male and ten female, competitive figure skaters ranging in technical classification (juvenile, novice, and senior) and age (10 to 26 yrs.) respectively, gave their informed consent to participate in the study (Appendix E). The criteria for subject eligibility included: (i) technically capable of executing the jumps stipulated in the experimental design, (ii) a competitive history of greater than 3 years duration, and (iii) currently injury free. Ethical approval for the study was granted by the Faculty of Physical Education & Recreation Ethics Committee at the University of Alberta.

Experimental Procedures

Skaters were asked to execute single, double, and triple revolution jumps, in a random order, to the best of their ability. All subjects wore their customary skates used for freeskate training. Landing impact data between the plantar surface of the foot and the insole of the skate was quantified with the use of the Micro EMED Insole System (*Novel GmbH, Munich, Germany*) at the maximum sampling frequency of a single insole (100 Hz.). The Micro EMED Insole System is a pressure distribution measuring device based on the capacitance principle (Nicol, 1977). Installation and operating procedures for single insole data collection were followed as outlined in the Micro EMED Manual (*Novel*

GmbH, Munich, Germany). The 2 mm thick insole, consisting of 85 capacitive sensors, was placed inside the skate of the landing foot, replacing the insole of the skate, and tethered to the leg with the data acquisition unit secured to the lower back of the subject (Figure 3a.1). During a standardized warm up, the skaters familiarized themselves with the experimental conditions and weight adjustment imposed by the experimental equipment. The insole was then "*zeroed*" and data was collected in "*Memory Mode*" as outlined in the manufacturer's specifications. Skaters were instructed to manually trigger the start of data collection using a hand held switch during the preparatory phase of the jump and to terminate data collection upon completion of the landing phase. Data was subsequently down loaded onto a 486 SX personal computer and stored for analysis upon completion of each trial.

The EMED Extern - Multimask Software Package was employed to process the Micro EMED data. Initially, the recorded data were examined for any indications of insole damage or equipment failure, and if no damage or failure was found, individual step files (*.STP) were made for further data analysis. A standard foot mask was used dividing the foot into two regions: rear foot (0-50% of the length of the pressure print) and forefoot (50-100% of the length of the pressure print) to assess foot fall patterns and time sequencing of peak forces (Figure 3a.2).

Impact forces and foot pressure data were analysed in three ways. The first analysis examined the group as a whole (n=24) and descriptively documented the results for the following variables: Peak impact force (%BW), Peak pressure (N/cm^2), Pressure time integral (Impulse-N/cm^2), Force time integral (Impact-%BW) and measures of the

Peak force-time differences between the fore and rear foot (ms). Secondly, a repeated measures - analysis of variance (3 groups {juvenile, novice, senior} x 2 sexes {male, female} x 3 jumps {singles, doubles, triples}) was performed to determine significant differences among the above listed variables, within-subjects and between groups as stipulated by their technical classifications. Level of significance was set *a priori* at $p \leq 0.05$. The third analysis estimated the magnitude of differences between groups using a standardized value of effect size (0.2 - small, 0.4 - mod., 0.8 - large) (Cohen, 1969).

Reliability Measures

Studies conducted by Barlett, Muller, Raschner & Brunner (1992b) and Hughes, Pratt, Linge, Clark & Klenerman (1991) have assessed and validated the suitability of the EMED F pressure insole for the measurement of the pressure distribution on the plantar surface of the foot during a range of throwing and jumping athletic events. A comparison between overall vertical forces measured by the EMED and a Kistler force platform revealed that the two followed very similar trends with identical values of peaks and troughs (Barlett *et al.*, 1992b). These authors also reported that the EMED insole gave a reasonable temporal resolution of pressure distribution when sampled at 100 Hz.

For the purpose of the present investigation, reliability of the Micro EMED System was evaluated under both static and dynamic conditions. A comparison of vertical forces obtained simultaneously by the Micro EMED Insole and a Bertec Force Plate - Model 4060A was conducted. In the static condition, the insole was placed on the surface of the force plate. The force plate and insole were loaded incrementally in both the ascending and descending directions with weights of 40, 80, 100, 80, 40 lbs., respectively. Figure 3a.3

illustrates the comparisons revealed.

In the dynamic condition, a single insole was secured to the sole of the subject's foot, tethered to the leg and the data acquistion unit secured to the lower back. The subject was instructed to land with the foot instrumented with the insole on the force plate and the opposite foot on an adjacent levelled area. The subject executed three jumps from each of three selected box heights (cm). Vertical forces were sampled at 100 Hz and 2000 Hz for the insole and force plate respectively in both static and dynamic conditions. Peason product moment correlational analysis revealed that vertical forces measured by both testing modalities were comparable ($r = .977$, $p \leq 0.05$).

A limitation of the data presented was the sampling frequency of the equipment employed. It was recognised that the sampling frequency of the Micro EMED Insole may be lower than desirable to capture impact for the type of activity assessed. However, it is the intent of this research to determine detectable differences in vertical force upon landings of differing revolutions, not quantify the exact vertical force upon impact. Of significance to the present study was the capacity of the testing equipment to support data acquisition of a sport specific skill, in the environment in which the sporting event is normally performed while training and/or competing. The merit of the testing equipment employed was ultimately related to its suitability to the given application. The thinness of the insole allowed it to be slipped into the skate without interfering with the normal fit of the skate. The weight of the equipment only marginally effected jumping ability which was overcome with practice. Overall, the instrumented insole presented an attractive method of registration of foot loading during on-ice jumping.

Results

Subject characteristics as defined by technical classifications are presented in Table 3a.1. As a result of the technical demands of the jumps performed, only the senior classification of skaters were capable of performing triple revolution jumps successfully. Therefore, the impact data obtained from single and double revolution jumps (n=24) were analysed across all three technical calibres of skaters and then subsequently compared with the impact forces of triple revolution jumps (n=7). Table 3a.2 displays mean values, standard deviations, and ranges of examined variables.

ANOVA results indicated that there was no significant main or interaction effect based on sex for any of the examined variables, thus male and female groups were collapsed for further analysis. Statistically significant differences in peak impact force (%BW) and time sequencing of foot contacts (ms) were found between groups and jumps ($p \leq 0.05$). An analysis of effect size examined the magnitude of the differences in impact force and force-time differences of triple revolution jumps as demonstrated by the Senior classification only. A range of moderate (.5) to large (1.3) differences in relative force and force-time differences between single, double, and triple jumps and technical classifications were detected.

An analysis of foot masks allowed the detection of distribution and sequencing of peak impact forces. The colour coded pressure prints (Figure 3a.4) revealed that in single and double revolution jumps, the highest or peak impact locations were exerted on the fore foot subsequently followed by a lower peak on the rear foot. The impact sequence was not as well defined in the triple revolution jumps. The landings of a triple revolution jump appeared to be representative of a collision-type landing, fore and rear foot impact occurring almost simultaneously, with the greater impact force being absorbed by the rear foot.

The sequencing of contact forces was also confirmed by examining the gait lines upon landing. Figure 3a.5 illustrates the gait lines of single and double revolution progressing from the fore to the rear of the foot print, whereas in a triple revolution jump it is difficult to determine the start, end, or the direction of the gait line, except for the fact that all peak force contacts were made behind the 50% mid line of the foot mask.

As illustrated in Figure 3a.6, an inverse relationship between relative peak impact force (%BW) and time differences between the fore and rear foot peak force contacts (ms) was observed. Mean impact forces (%BW) were absorbed over greater periods of time for single revolution jumps in comparison to the multi-revolution jumps.

Discussion

Results of the present investigation indicated that peak impact force (%BW) obtained during the landing phase of on-ice jumping increased with technical calibre, as defined by the number of revolutions completed while airborne. An inspection of data in Table 3a.2 indicated that not only did the mean force values analyzed by group increase with additional revolutions, the range of impact forces, although represented by large individual variations, also displayed an upward trend.

The relationship between relative impact force (%BW) and time delay between fore and rear foot contacts (ms) showed that as peak impact force increased, the time taken to distribute the force became significantly shorter. Although jump height was not quantified as a primary purpose of this investigation, subsequent kinematic analysis revealed that jump height was not significantly different among single, double, and triple revolution jumps. A three dimensional kinematic analysis by King, Arnold & Smith (1994) also reported that increased revolutions in double and triple on-ice jumps are accomplished by increasing rotational velocity, not height or time in the air. Therefore increased height is not suggested as a possible cause of higher impact force or shorter foot fall time. It is proposed, however, that the increased time required for additional rotation places the skater closer to the ice at the time of impact. As a result, the skater has less time to prepare and execute the landing phase of the jump. Therefore, a "collision type" landing occurs more frequently during the execution of multi-revolution jumps. Decreasing the time to properly dissipate the magnitude of the impact force may also suggest that the impact propagated through the lower extremity musculo-skeletal system introduces greater potential for injury.

During the landing phase, an optimal body position at the initial point of contact is characterized by a tight upright body, with hips and knees maximally extended, legs crossed at the mid calf, and ankles plantar flexed. This position allows for optimal lower extremity joint flexion, sequencing of joint flexion upon impact and thus, maximal impact absorption. The kinematic data presented in Chapter IIIb confirmed that this technique was observed during the execution of the single jumps and to a lesser degree, the double revolution jumps. In contrast, the landings of triple revolution jumps demonstrated a signficantly greater degree of flexion at both the knee and the hip joints of the supporting leg, at the time of impact. No significant difference was seen in ankle flexion between jumps, however, this was attributed to the stability of the skate acting as a mechnical block to increased ankle flexion. Although built to provide support, the boot seems to be introducing a barrier, allowing only minimal attenuation of impact to occur at this location. Furthermore, the shock wave pattern of flexion from distal to proximal joints which normally occurs as a result of landing, was not evident in multi revolution on-ice landings. Maximal ankle flexion was preceded by flexion at the hip, followed by the knee. Therefore, impact absorption appeared to be attenuated primarily by the hip joint.

Conclusions

The present research investigated the magnitude of loading during the execution of on-ice jumps of single and multi-revolutions. Although the landing styles of single, double, and triple revolution jumps are proposed as being technically identical, the kinetic data revealed that the skaters' execution of these skills were dissimilar and could be potentially injurious. "Soft landings" or landings exhibiting lower impact forces over a longer period of time were displayed in single revolution jumps. In contrast, the landings of multi-revolution jumps appeared to be representative of a harder collision-type landing, demonstrating a greater impact force over a short time-history sequence. The kinematic analysis also revealed that landing impact was absorbed in a unique manner dependent upon the calibre of the jump executed. A complete kinematic description of the biomechanics of on-ice landings is outlined in a subsequent paper.

From a coaching perspective, it may be recommended that coaching guidelines include a learning progression of specific prerequisite skills inherent in impact absorption techniques, more commonly referred to as "safe landings". It is further recommended that these skills be mastered by the athlete prior to the training of technically challenging, multi-revolution jumps to eliminate the potential for mechanical load-type injuries.

References

Barlett, R.M., Muller, E., Raschner, C. & Brunner, F. (1992b). The suitability of the EMED insole for the measurement of pressure distribution on the plantar surface of the foot during athletic throwing and jumping events. *Communication to the 9th Congress of the International Society of Electrophysiological Kinesiology*, August, Baltimore.

Cohen, J. (1969). Statistical Power Analysis for the Behavioural Sciences. New York: Academic Press.

Dufek, J.S. & Bates, B.T. (1991). Biomechanical factors associated with injury during landing in jump sports. *Sports Medicine*, **12**(5), 326-337.

Forwood, M. & Burr, D. (1993). Physical activity and bone mass: exercises in futility? *Bone and Mineral*, **21**, 89-112.

Hughes, J., Pratt, L., Linge, K., Clark, P. & Klenerman, L. (1991). Reliability of pressure measurements: the EMED F system. *Clinical Biomechanics*, **6**, 14-18.

King, D., Arnold, A. & Smith, S. (1994). A kinematic comparison of single, double, and triple axels. *Journal of Applied Biomechanics*, **10**, 51-60.

McNitt-Gray, J. (1991). Kinematics and impulse characteristics of drop landings from three heights. *Int. Journal of Sport Biomechanics*, 7, 201-224.

Nicol, K. (1977). Druckverteilung uber den Fuβ bei sportlichen Absprungen and Landungen in Hinblick auf eine Reduzierung von Sportverletzungen (Pressure distribution over the foot during sport takeoffs and landings with regard to a reduction in sport injuries).
Leistungsport, 7, 220-227.

Novel Electronics Inc. EMED User Manual. 1994; Minneapolis.

Panzer, V.P., Wood, G.A., Bates, B.T. & Mason, B.R. (1988). Lower Extremity loads in landings of elite gymnasts. In: Groot, G. et al. (Eds.), *International Series on Biomechanics, Biomechanics XI-B* (pp 727-735). Free University Press, Amsterdam.

Radin, E., Parker, H., Pugh, G., Steinberg, R., Paul, I. & Rose, R. (1973). Response of joints to impact loading - III. *Journal of Biomechanics*, **6**, 51- 57.

Robbins, S. & Gouw, G. (1990). Athletic footwear and chronic overloading. *Sports Medicine*, 9, 76-85.

Table 3a.1 Subject Characteristics (n=24). Values are reported as Means ± Standard Deviations.

Technical Classification:	**Juvenile (n=6)**	**Novice (n=11)**	**Senior (n=7)**
Age (yrs.)	11.33 ± 1.37	16.73 ± 2.80	20.57 ± 4.16
Mass (kg.)	39.53 ± 5.65	60.10 ± 5.28	66.33 ± 13.03
Jumps Performed	Singles Doubles	Singles Doubles	Singles Doubles Triples

Table 3a.2 Impact Data. Values are reported as Means ± Standard Deviation.

Number of Revolutions **Number of Subjects**	**Single** **(n=24)**	**Double** **(n=24)**	**Triple** **(n=7)**
Range of Raw Force (N)	979 - 5857	1086 - 5760	3469 - 5388
Peak Impact Force * (%BW)	5.1 ± 1.48	5.3 ± .38	5.8 ± 1.18
Range of Impact Force (%BW)	2.49 - 7.16	2.99 - 6.65	3.77 - 7.25
Peak Pressure * (N/cm2)	63.5 ± 18.63	63.92 ± 18.52	71.14 ± 15.73
Force-Time Difference * (ms)	101.29 ($\bar{x}$)	43.33 ($\bar{x}$)	27.86 ($\bar{x}$)

* Significant differences were found between single, double, and triple revolution jumps ($p \leq 0.05$)

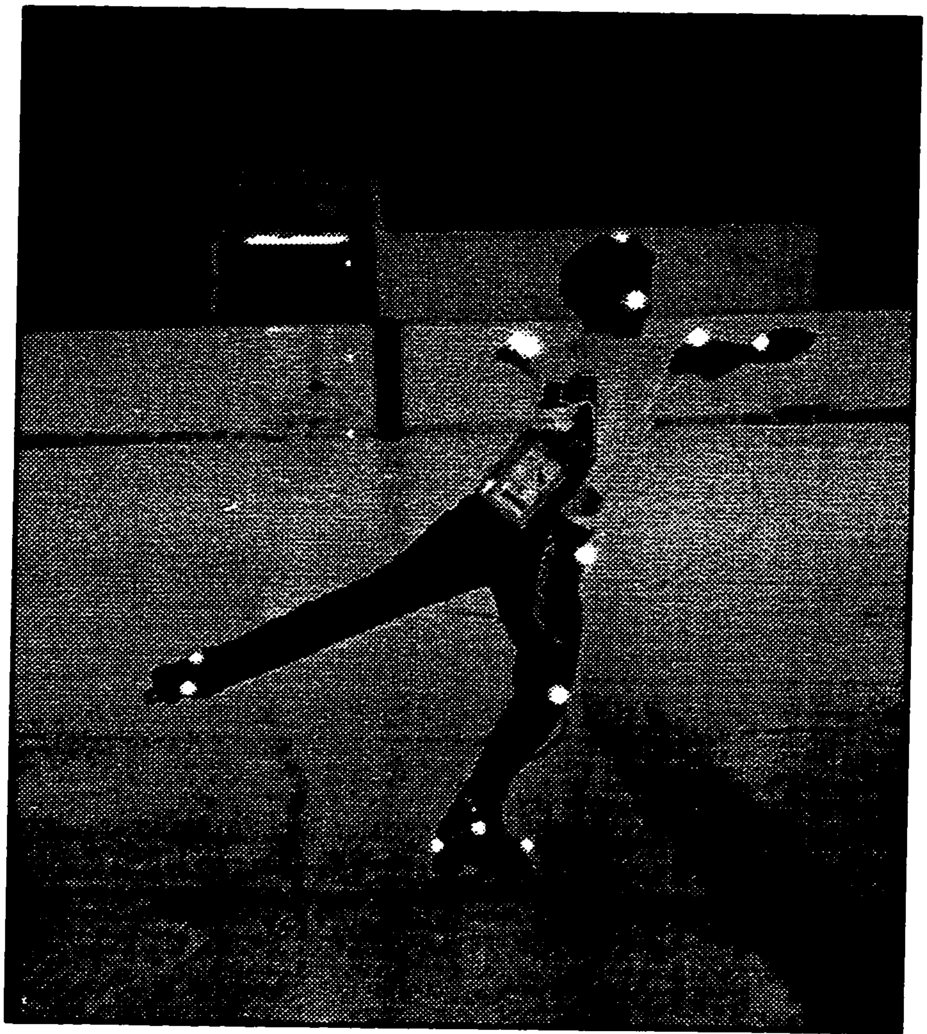
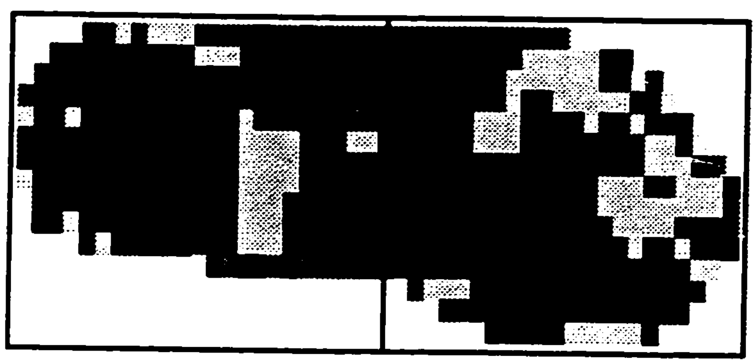


Figure 3a.1 Landing position executed while instrumented with the Micro EMED System.

Rear Foot



Fore Foot

Mask #1
0 - 50 % of pressure print

Mask #2
50 - 100% of pressure print

Colour ■ >30 ■ >22 ▨ >15 ■ >10 ■ >6 ■ >4 N/cm²

Figure 3a.2 Standard mask used to analyse pressure print of Micro EMED Insole.

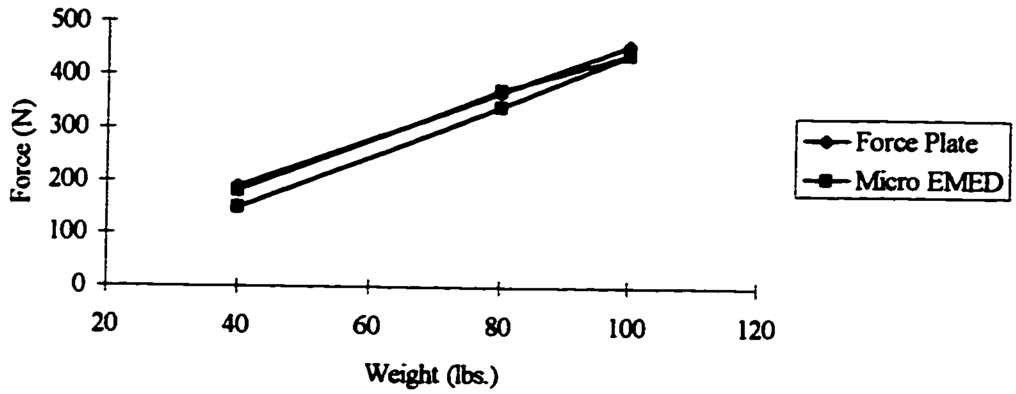


Figure 3a.3 Force values (N) measured during static incremental loading of 40, 80, and 100 pound free weight plates in both the ascending and descending directions by a Bertec Force Plate - Model 4060A and the Micro EMED Insole.

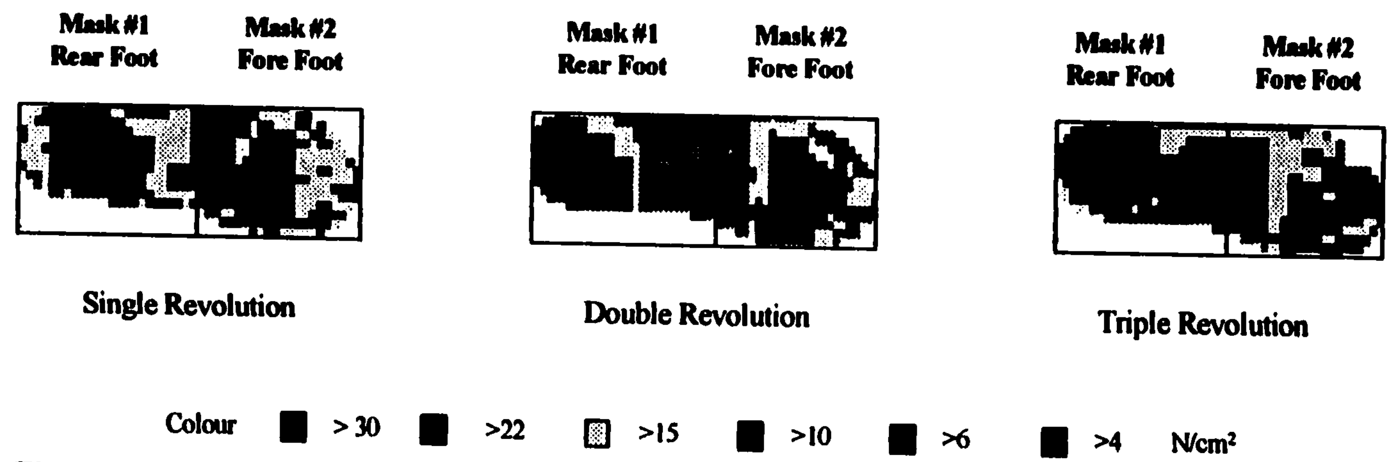
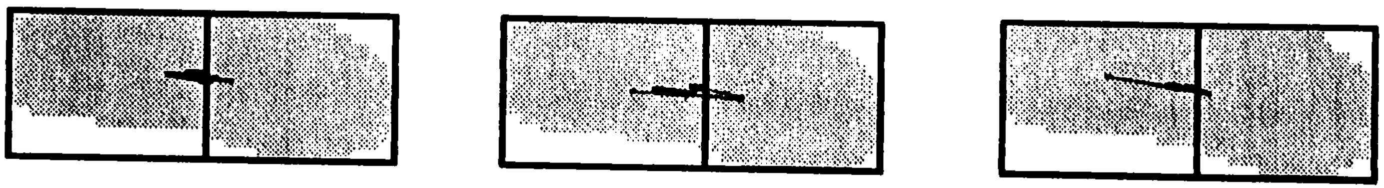


Figure 3a.4 Colour coded pressure prints of impact forces (N/cm^2) for single, double, and triple revolution jumps.



Single Revolution　　Double Revolution　　Triple Revolution

Figure 3a.5 Gait lines during the landing phase of single, double, and triple revolution jumps.

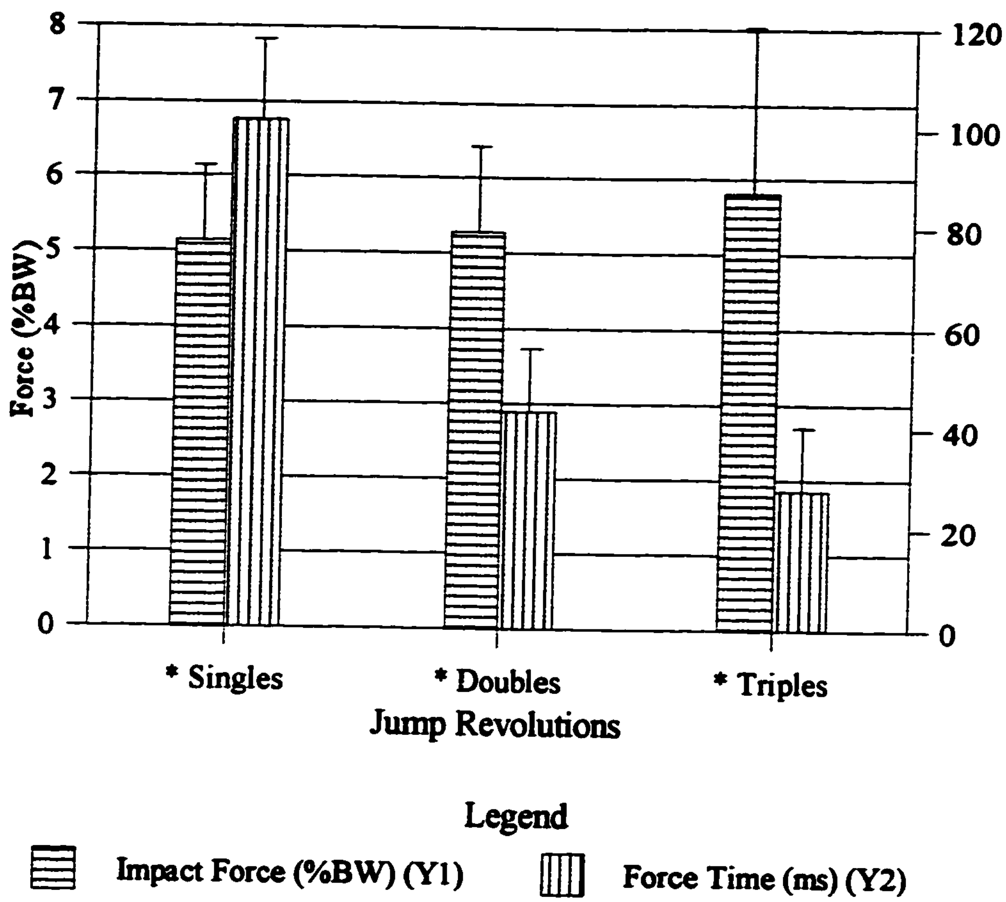


Figure 3a.6 Inverse relationship between impact force (%BW) and force time (ms) contacts of the fore and rear foot. Values are reported as Mean ± Standard Error.

* Significant differences were observed between single, double, and triple revolution jumps ($p \leq 0.05$).

KINEMATIC CHARACTERISTICS OF IMPACT ABSORPTION UPON LANDING MULTI-REVOLUTION JUMPS IN FIGURE SKATING

Abstract

Landing kinematics of single, double, and triple revolution jumps were determined from spatial analysis to assess the impact absorbing charactertistics employed by skaters during the execution of landing on-ice jumps. Landing requires the skaters to absorb the mechanical forces of impact backwards, on a single leg, in a technically prescribed configuration for an extended period of time. Maintaining the speed, glide, and flow that was created upon takeoff is a quality deemed of importance in the evaluation of a technically well executed landing. Three national calibre male figure skaters were recruited to perform single, double, and triple revolution jumps to the best of their ability. The landing phase was defined from the initial point of contact to time when the skater acquired a relatively stable, technically prescribed landing position. An analysis of lower extremity joint flexion and joint sequencing revealed that although landings are coached to be technically identical in all jumps performed, skaters exhibited unique landing stategies on single versus multi revolution jumps. In single revolution jumps, sequencing of joint flexion progressed from distal to proximal with all lower extremity joints contributing to the movement, however the degree of knee and hip flexion was significantly greater than the ankle. In contrast, in multi revolution jumps, the ankle, knee, and hip joint do not contribute equally nor do they sequence in an efficient manner to maximally absorb the forces of impact. Maximal flexion was seen primarily at the knee and hip joint, almost occuring simultaneously. Ankle flexion was minimal. This trend was consistent in all skaters examined. It was proposed that the skating boot acts as a mechnical block, inhibiting ankle flexion and thus sequencing of lower extremity joint flexion, limiting their contribution to impact absorption.

Key Words: *Figure skating; Landing; Kinematics; Multi-revolution jumps*

Introduction

To date there has been a limited number of contributions made to our understanding of the mechanics of on-ice jumping in the sport of figure skating. Furthermore, biomechanists have primarily investigated the approach, takeoff (Albert & Miller, 1996) and flight kinematics (King, Arnold & Smith, 1994) of on-ice jumping and placed minimal emphasis on the landing phase and impact absorption.

A previous study was undertaken to quantify the impact forces upon landing single, double, and triple revolution jumps during on-ice jump training in competitive figure skaters (Lockwood & Gervais, 1995). Landing impact was quantified using the Micro EMED System *(Novel Gmbh, Munich, Germany)*. The results revealed that the magnitude of impact significantly increased with additional revolutions ranging from 3 to 9 times the skater's respective body weight. In addition, two distinctly different landing techniques were identified: soft landings producing less force for a longer period of time, and hard landings characteristized by a collision type of contact. Decreasing the time to properly dissipate the force in multi-revolution jumps may suggest that the impact propagated through the lower extremity musculo-skeletal system was of greater magnitude and intensity introducing greater potential for injury.

Shock moderating behaviours or the desirable reduction of forces are commonly adopted as protective mechanisms of the human body in reducing peak forces during landings (Lees, 1981). These strategies are a result of complex interactions between the links or segments of the body. Therefore, the purpose of the present study was to compare and contrast the kinematic profiles of landing positions of single and multi-revolution jumps. A three dimensional kinematic analysis was performed to examine the influence of impact on kinematic variables and the possible parameters responsible for the effectiveness of the individual to dissipate impact forces. Furthermore, the present research investigated how the body segments interact with each other, the restraints imposed by the skate, and the technique utilized by these athletes in producing soft versus hard landings. It was hypothesized that differences in the kinematic profiles of landing single versus multi-revolution jumps, specifically hip, knee, and ankle flexion will be observed among these athletes.

Methods and Procedures

Subjects

The three national calibre male figure skaters recruited for this investigation were participants of the previous project (Chapter IIIa: "Quantification of Impact Forces upon Landing Single, Double, & Triple Revolution Jumps in Figure Skaters"). These subjects volunteered to perform single, double, and triple revolution jumps for the purpose of this investigation. Subjects ranged from 16 - 26 years of age, from 48.5 - 89.5 kilograms in body mass, and from 160 - 188 centimetres in height. Ethical approval was granted from the Human Ethics Review Committee in the Faculty of Physical Education & Recreation at the University of Alberta.

Experimental Procedures

Prior to data collection, 19 light weight reflective markers 1 centimetre in diameter were secured to 19 anatomical and boot landmarks on each subject to aid the digitizing procedures. A cubic area of 6 metres by 4 metres by 2.5 metres in height was defined as the jump space. This space was calibrated with a three dimensional array of markers with known position coordinates. The experimental set up is illustrated in Figure 3b.1. Upon completion of a standardized warm-up, the skaters were instructed to execute single and multi-revolution jumps to the best of their ability, in a random order and complete the landings in their typical form. Skaters were video taped performing three trials of each jump by four Panasonic cameras at a frequency of 60 frames per second (fps). The cameras were positioned in a rectangle, 90 degrees to each other respectively, surrounding the calibrated jump space. Four 1000 watt halogen lights were used as external lighting in addition to the arena house lights and located beside each camera. A light placed in the field of view was manually activated during the airborne phase of the jump to allow for synchronization of video records. The four views of each jump trial were then manually digitized using the Ariel Performance Analysis System. Three dimensional coordinates for 15 segmental endpoints were calculated using Direct Linear Transformation (DLT)(Abdel-Aziz & Karara, 1971) and data was subsequently smoothed using a quintic spline.

The complexity of the skill of landing demanded the isolation of component variables which were evaluated for their contribution to the attenuation of impact. For the purpose of this analysis, the internal angles of ankle flexion, knee flexion, and hip flexion were selected for comparison (Figure 3b.2). In addition to the magnitude of joint segment angles, the time-sequencing or kinematic time-history displayed at the point of impact and maximal flexion prior to stabilization of the landing phase were determined and compared among jumps executed.

Statistical Analysis

Due to the limited number of subjects in this analysis, only basic descriptive statistics were performed. This analytical approach eliminated the possibility of individual subject trends from being masked by group mean data.

Results and Discussion

Individual data illustrated that comparable performance strategies in shock absorbing mechanisms were utilized by all of the skaters examined. Maximum knee and hip flexion increased with the complexity of the jump, whereas ankle flexion was minimal (Figure 3b.3). The shock wave pattern of flexion from distal to proximal joints, which normally occurs as a result of landing, was demonstrated in single revolution jumps. However, this was not evident in multi-revolution on-ice landings. Peak ankle flexion was preceded by flexion at both the knee and hip joints in jumps of higher impacts.

Previous research has identified that high frequency impact forces (shock) are influenced by several factors including; kinematic positions, equipment (eg., skate structure), and landing surface (Dufek *et al.*, 1993). Trends in these data seem to confirm that all the aforementioned factors may influence the performance strategies employed by these athletes in an attempt to attenuate impact upon landing. Positional data demonstrated that the body increases the degree of flexion of the lower extremities when exposed to greater impacts with the exception of ankle flexion. The stability of the boot appeared to provide a mechanical block to increased ankle flexion. Although thought to provide support, the boot may be introducing a barrier allowing only minimal attenuation of impact to occur at this location and furthermore interrupting the normal sequencing of shock absorption.

Despite the advancing performance demands of on-ice jumping, technological improvements of equipment have been limited. Richards (1996) stated that, since the turn of the 19th century, the basic design and structure of the figure skating boot has changed minimally. A longitudinal account of boot structure and design revealed that in response to the more dynamic nature of competitive figure skating, boot manufacturers have responded to the athletes demands by making the boot considerably heavier and stiffer (Smith & Richards, 1996). These changes were intended to improve the lateral support of the boot, however this also limited the degree to which a skater can dorsi- or plantar-flex the ankle. These results concurred with earlier work by Foti (1990) who compared peak vertical impact forces and joint angular positions during simulated figure skating landings, executed in a traditional boot versus an articulated joint boot. Foti (1990) theorized that the articulated boot would allow a greater range of ankle motion during the landing than the conventional boot and therefore enable greater force attenuation. However, it was determined that although peak vertical impact force was significantly decreased, the time taken to absorb the force was unchanged revealing no difference between the articulated and conventional boot in time.

Soft landings, as demonstrated in single revolution jumps, are defined by Ozguven & Berme (1988) as phased segmental deceleration and muscular activity anticipating the impact. In contrast, the multi-revolution jumps appeared to be representative of a harder landing, demonstrating a unique flexion time-history sequence. Peak flexion of the hip and knee occurred simultaneously, followed by ankle flexion. As observed in other investigations conducted on hard surfaces (Dufek & Bates, 1993), there was a marked increase in joint flexion and an appreciable amount of give in the upper body during on-ice landings.

Conclusions

Landing from a jump imposes forces on the body that must be absorbed primarily by the musculo-skeletal components of the lower extremities (Dufek & Bates, 1991). The present research attempted to include lower extremity joint kinematics and landing technique to better understand the mechanisms used to accommodate the forces applied to the body during the landing of on-ice jumps of single and multi-revolutions. The data presented revealed that parameters altered as a result of greater impact forces upon landing included both the degree of joint flexion and the sequencing of joint flexion. Although the natural landing styles of single, double, and triple revolution jumps are technically similar, the body's reaction or attempt to absorb the shock of greater impacts altered the landing position and performance strategy. Joint flexion was primarily seen at the knee and hip, indicating a significant amount of shock absorption occurred at these sites.

It is suggested that the magnitude of impact forces produced during landings from jumps while skating theoretically can be reduced by changing the landing technique used. During the landing, the vertical momentum of the skater's body is reduced to zero by the ground reaction force produced. This change in momentum is related to the force over time, as stated in Newton's Second Law. When the skater lands with a rigid body, all the body segments decrease their velocity together, over a very short period of time. Because the total time over which the change in momentum takes place is small, the force magnitude is large. However, if the skater flexes each body joint in a sequential manner and thereby increases the time over which the impact takes place, the force magnitude will be relatively smaller. Several authors have suggested that this ability to effectively absorb shock during landing is learned (Mizrahi & Susak, 1982; Lees, 1981). Therefore, training is important in order to establish a preprogrammed muscular response which will be effective in reducing impact forces. As a result of the observations of the present study, it may be recommended that coaching guidelines include a learning progression of specific prerequisite skills inherent in impact absorption techniques. These should be mastered by the athlete prior to training for the execution of multi-revolution jumps.

The present investigation supports the use of kinematic analyses as useful tools for documenting and evaluating biomechanical behaviour in figure skating. Similar analysis may also be recommended to gauge the effect of equipment on performance. In future kinematic research, a larger sample population would allow us to address the question of whether the observed landing kinematics of the study are a result of a strategies learned in training or a mere consequence of impact loading. Further research would also establish the risks of long-term exposure to shock and absorption mechanisms.

References

Abdel-Aziz, Y,I. & Karara, H.M. (1971). Direct linear transformation from comparative coordinates into object space coordinates in close-range photogrammetry. *In proceedings of the American Society of Photogrammetry Symposium on Close Range Photogrammetry* (pp.1-18). Fall Church, VA: American Society of Photogrammetry.

Alberta, W.J. & Miller, D. I. (1996). Takeoff charactertistics of single, and double axel figure skating jumps. *Journal of Applied Biomechanics*, 12: 72-87.

Dufek, J.S. & Bates, B.T. (1991). Biomechanical factors associated with injury during landing in jump sports. *Sports Medicine*, 12(5): 326-337.

Dufek, J. , Schot, P. & Bates, B. (1993). Landing performance, Part II: Assessment and future directions. *Medicine, Exercise, Nutrition & Health*, 2: 135-142.

Foti (1990). The biomechanical evaluation of landings in an articulated boot figure skate. Unpublished Master's Thesis, University of Delaware.

King, D.L., Arnold, A.S. & Smith, S.L. (1994). A kinematic comparison of single, double, and triple axels. *Journal of Applied Biomechanics*, 10: 51-56.

Lees, A. (1981). Methods of impact absorption when landing from a jump. *Engineering in Medicine*, MEP, 10(4): 207-211.

Lockwood, K. & Gervais, P. (1995). Quantification of impact forces upon landing single, double, and triple revolution jumps in figure skating. In *Proceedings of the International Society of Biomechanics (ISB)*, (pp. 566-567), Jyvaskyla, Finland.

Mizrahi, J. & Susak, Z. (1982). Analysis of parameters affecting impact force attenuation during landing in human vertical free fall. *Engineering in Medicine*, 11: 141-147.

McNitt-Gray, J. (1991). Kinematics and impulse characteristics of drop landings from three heights. *International Journal of Sport Biomechanics*, 7: 201-224.

Ozguven, H. & Berme, N. (1988). An experimental and analytical study of impact forces during human jumping. *Journal of Biomechanics*, 21(12): 1061-1066.

Radin, E., Parker, H., Pugh, G., Steinberg, R., Paul, I. & Rose, R. (1973). Response of joints to impact loading -III. *Journal of Biomechanics*, 6:51- 57.

Richards, J. (1996). Effects of ankle mobility on landing forces in skating. In *Proceedings of the International Congress on the Sports Medicine and Sports Science of Skating*, San Jose, Calif.

Robbins, S. & Gouw, G. (1990). Athletic footwear and chronic overloading. *Sports Medicine*, 9: 76-85.

Smith, A. & Richards, J. (1996). An articulated skate boot. In *Proceedings of the International Congress on the Sports Medicine and Sports Science of Skating*, San Jose, Calif.

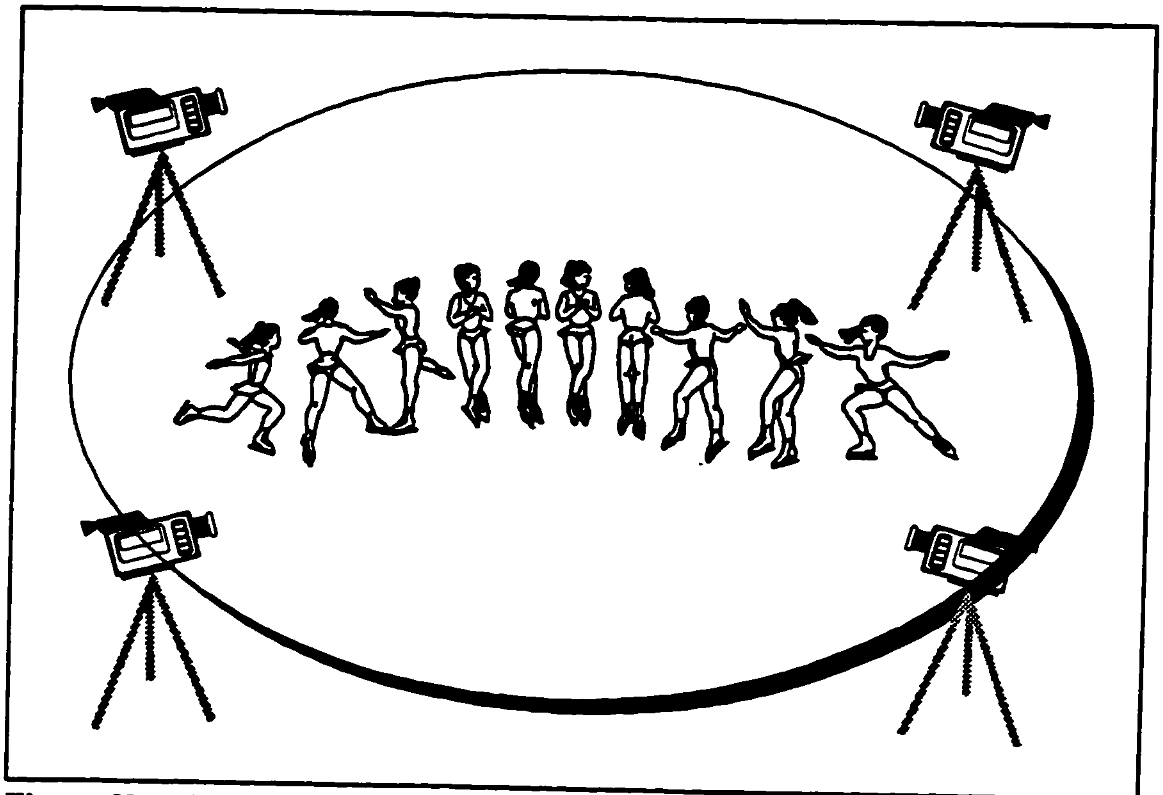


Figure 3b.1 Video Taping Site: The size of the filming site was determined by the area required by the skaters to execute single, double, and triple revolution jumps. For the purpose of this study an area of 6 metres by 4 metres by 2.5 metres in height was established. Four Panasonic cameras were positioned on the ice, at 90 degrees to one another, repectively.

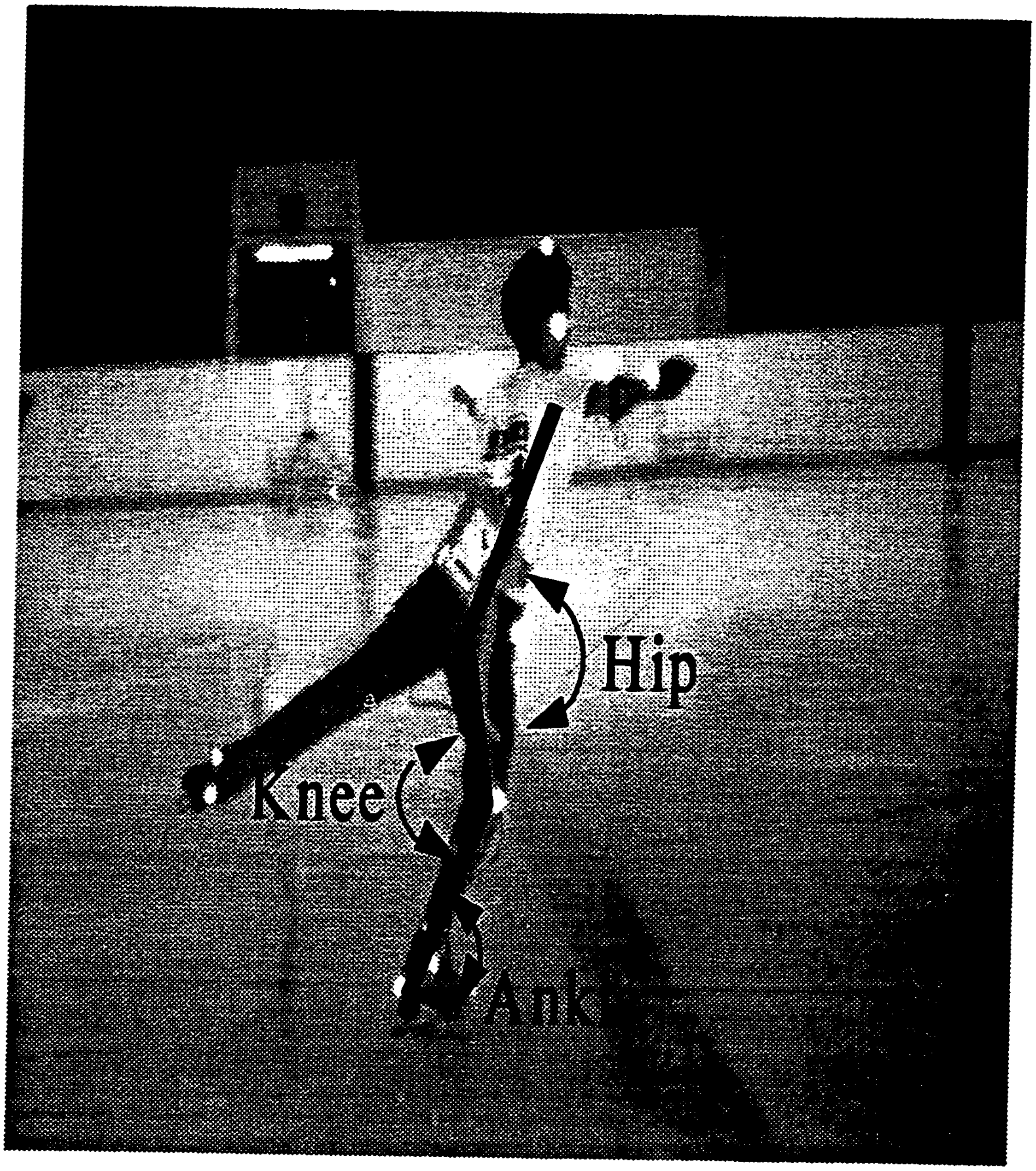


Figure 3b.2 Landing Position: Internal angles of the hip, knee, and ankle analysed.

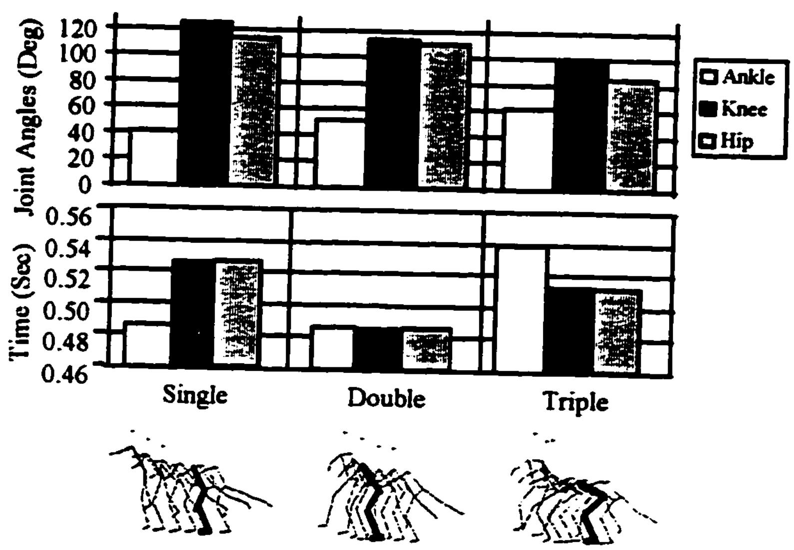


Figure 3b.3 Relationship between joint angles and time of joint flexion during the landing phase: (i) peak joint angles, (ii) time sequencing of peak joint flexion, and (iii) stick figures representing the entire landing phase.

CHAPTER FOUR

Physiological Profiles of Competitive Figure Skaters

Project III

PHYSIOLOGICAL PROFILES OF COMPETITIVE FIGURE SKATERS

PHYSIOLOGICAL PROFILES OF COMPETITIVE FIGURE SKATERS

Abstract

The increasing technical demands placed upon competitive figure skaters to consistently perform flawless programs has created a need for a greater understanding of the physiological attributes required by these athletes. In the present study, 55 competitive figure skaters ranging in age from 10-26 years and technical calibre from juvenile to senior national levels were evaluated to profile selected physiological qualities. Subject assessments were based upon the collation of data from physiological fitness evaluations and autobiographical questionnaires. Mean values of designated fitness parameters of the four successive technical calibres of skaters were compared. Parallel trends of increasing age, size, and maturation with increasing technical calibre were clearly delineated. As expected, the training frequency, duration, and intensity of both on-ice and off- ice training increased with advancing calibre as indicated by autobiographical questionnaires. The physiological variables deemed important to on-ice performances also increased significantly with advancing calibre ($p \leq 0.05$). Senior skaters possessed greater cardiorespiratory fitness, anaerobic power, leg strength, and flexibility. A significant effect of sex was observed among all variables examined indicating that males had superior scores on all tests with the exception of flexibility. Although it was difficult to ascertain the relative contribution of training versus growth and development to several of the characteristics evaluated, the linear relationship between physiological variables and technical calibre would tend to support the contribution of sport specific training to physiological form. Retrospective training profiles revealed that all skaters evaluated trained an average of 10.5 months per year and the mean starting age of competitive training has becoming significantly younger ($p \leq 0.05$) in this group. Senior calibre skaters started their training at the mean age of 7.7 years, whereas the juveniles of today started training at the mean age of 5.8 years. Therefore, it could be concluded that not only are the demands of the sport increasing, athletes of younger age and physical maturation are training to meet these demands.

***Key Words:** Figure Skaters; Physiological Profiles; Performance.*

Introduction

Unlike several Olympic sports where performance is solely based on a quantitative score or result achieved by the most physically capable and skilled athlete, the sport of figure skating incorporates a physical, a technical, and an aesthetic component into the performance outcome. Although the exact contribution of each variable to performance outcome is difficult to establish, a minimum standard has been deemed important to assess. The technical and artistic standards are extremely well defined within the context of the sport, however, authors and coaches agree that it is no longer adequate to describe figure skating performances on the basis of technique and artistry alone. Over the past decade, the heightened physical demands placed upon today's competitive figure skaters have promoted the growth and acceptance of figure skating as a physically demanding sport rather than a physical art form. Competitive success demands both physiological preparedness and technical efficiency.

Athletes competing in different sports often have different physiques and physiological development. Furthermore, athletes performing at different levels in the same sport may have similar traits but differ in the extent of their expression (Hawes & Sovak, 1994). The causes of these differences have been attributed to influences such as genetic endowment, physical training, nutrition and socio-cultural factors. Since the contribution of such influences to the resulting structure are undefined, as is their relationship to performance, this often leads researchers to the question of whether the resulting physiques and physiological profiles are a reflection of the athlete's choice of sport or training within a sport and optimally, whether we can predict outstanding performance and athletic ability from physiological profiles.

The concept of introducing a physiological prototype in relationship to the development of young athletes has been used in several sports. Numerous studies have profiled Olympic champions, typically presented in variables that are both discrete and sensitive to change over a period of time. The purpose of physiologically profiling groups of athletes is (i) to assist in the understanding of human variance related to physical performance, (ii) as an indicator of change occurring as a result of sport specific training, (iii) to serve as a model for guiding the physiological development of future participants, and (iv) to aid in identifying individuals with exceptionally well suited physiological attributes for the given sport.

In the sport of figure skating, there has been limited contribution made to research knowledge in this domain. Several researchers (Gordon *et al.*, 1969; Ross *et al.*, 1976a; 1976b; 1977, Woch *et al.*, 1979; Niinimaa *et al.*, 1979; Patton *et al.*, 1986; and Gledhill *et al.*, 1992) have profiled preferred physiological characteristics of select groups of figure skaters as outlined in Table 4.1. These accounts have focused on designated groups of skaters without contrast between gender, maturation, calibre, or technical competency. Therefore, the relationship between the technical performance and physiological requirements and the physique of the successful athletes has yet to be clearly defined in this sport.

It has been widely accepted in competitive sport that a minimum level of physical readiness is required to perform successfully and to limit the incidence of injury. However, the appropriate age and technical level has yet to be determined. Since figure skating has become more physically demanding, it may be expected that the physical requirements of performance have changed in order for skaters to continue performing winning routines. It has been suggested that at moderate levels, physiological profile alone does not determine performance and that certain technical performance criteria would be more important (Gledhill *et al.*, 1992). However, if all other factors are equated, then physical differences may have the potential to explain differences in performance.

The increased emphasis on more challenging performances in younger figure skaters has contributed to several concerns about the health of young athletes. Smith (1996) reported that off-ice training and increased levels of physiological fitness markedly reduced the incidence of serious injuries sustained by an elite group of skaters from 1.2 to 0.5 injuries per team per season. This reduction was attributed to the increased rates of strength, flexibility, and knowledge. Therefore, it is the purpose of the present research to outline a profile of competitive figure skaters at successive levels of competitive and technical competency. Beyond the research incentive, this information would also be extremely valuable to the coach and athlete. Physiological profiles representing a prototype in a particular sport become a useful tool in the arsenal of the coach and sport scientist. It would provide a model against which improvements may be measured and an ideal to strive for. The concept may be used to monitor the training effect for individual athletes, recognize the limitation or the advantages to skill performance, and motivate during times when other quantitative measures of improvement are lacking.

Methods and Procedures

Subjects

Fifty five competitive figure skaters (37 females and 18 males) ranging in age from 10-26 years and in technical calibre from juvenile to a senior national level gave informed consent to participate in this study. The study was approved by the Faculty of Physical Education & Recreation Ethics Committee at the University of Alberta. Subject descriptive characteristics are illustrated in Table 4.2.

Individual Inventories

Autobiographical data, obtained from individual inventories, provided a criteria upon which groups could be subdivided for further analysis (eg. maturation status, starting age of training, years of training, hours of training per week, months of training per year), descriptively profiled the athletes studied, and provided support for quantitative data. Although there are obvious limitations with retrospective questionnaires, the autobiographical approach used in this test protocol has been shown to promote reliable and accurate recall by subjects (Grimston *et al.*, 1991). The four questionnaires administered to all participants are described as follows:

1) Maturity Index: Maturational status was determined using a self assessment maturity rating system (Bailey *et al.*, 1994). Subjects were given drawings and written descriptions of the five stages of pubic hair development and selected the drawings that most accurately reflected their current appearance (Appendix F). Prior to the completion of this assessment, verbal instructions were given to the subjects by the investigator. The use of self reported methods has been validated in a population of both male and female early adolescents by Schlossberger *et al.* (1992) and has been supported because it respects the concerns related to adolescent privacy.

2) Dietary Calcium Analysis: Calcium assessments were conducted in accordance with the protocol described by Thorvaldson (1990) (Appendix G). Subjects and parents were instructed on how to complete the Calcium Food Frequency Questionnaire. Subjects were asked to record the frequency of all items listed. An interview with parents and subjects immediately after the completion of the record was conducted to clarify any inconsistencies and resolve potential inaccuracies. Dietary Calcium Food Frequency records of each subject were coded and analysed as outlined in Appendix G.

3) Training/Activity Logs: An activity questionnaire developed for the use in this study was modified from questionnaires previously reported in the literature (Grimston *et al.*, 1993). Questions assessed year round training patterns, with additional questions regarding the average hours spent in non-weight bearing activities such as sleeping, doing homework, watching television, transportation to and from school or training venues, etc. (Appendix H). Week days were distinguished from weekend days. Specific information regarding sport specific training (eg., frequency, duration, and intensity) was included and responses confirmed with the athletes' coaches. All participants were asked to complete the activity questionnaire in collaboration with either their parents and/or their coaches.

4) Menstrual History (females only): Age of the onset of menses and the degree to which menstrual cycles could be classified as regular were determined by a written questionnaire (Appendix I). Regular menses for this age group were defined as 10-14 cycles per year.

Physiological Assessment

The physiological fitness assessment included measures of body composition, cardiorespiratory fitness, muscular strength, anaerobic power, and flexibility as outlined in the following descriptions. The test batteries were selected based upon their validity and reliability, in addition to their ability to evaluate the physiological variables deemed important to the performances of competitive figure skaters. Prior to the actual testing session, all subjects were familiarized with the testing equipment and protocols.

1) Body Composition Measures: The measures selected provided information on the general external morphology of the body as well as providing an indirect means of assessing internal body composition.

a) Standing height (measured ± 0.5 cm.)

b) Body mass (measured ± 0.2 kg.)

c) Girth (chest, waist, hips, thigh, calf, ankle, upper arm) (measured ± 0.1 cm.)

d) Skinfold measurements: (triceps, biceps, subscapular, supra iliac, abdominal, front thigh, mid calf, rear thigh [females only], chest [males only]) (measured by Harpenden Skin Fold Caliper ± 0.2 mm.)(Heyward & Stolarczyk, 1996). Percent body fat was calculated using the Yuhasz formula (Yuhasz, 1974).

e) Body Mass Index (BMI): Ratio of the person's weight (kg) to the height squared (m^2) (Keys, 1972).

2) Cardiorespiratory Fitness: Maximal oxygen consumption (VO_2 max) was determined on a treadmill and expired gases collected and analysed by a MMC Horizon ™ System (SensorMedics, California, U.S.A.) calibrated before and after each test. The test was preceded by a 5 minute warm-up phase at 5 mph, followed by a single, continuous, progressive protocol of 2% grade every two minutes as described by Thoden (1991). Speed of running was determined by the subject during the familiarization period. Previous testing conducted on figure skaters of the same age range in our laboratory indicated speeds of 5.5 to 7.5 mph were comfortable. Minute heart rate values were monitored and recorded by a calibrated telemeter heart rate monitor (Polar Pacer HRM ™, Polar USA, Inc., Stamford, CT). Continued increments were administered until there was no further increase in VO_2 with an increase in workload or volitional exhaustion occurred. Secondary criteria for the test to be discontinued included a respiratory exchange ratio of greater than 1.1 and age predicted maximal heart rates.

3) Muscular Strength Measures: Isokinetic strength testing was conducted using the Biodex Isokinetic Dynamometer. Peak torque (Nm) of both left and right knee extension and flexion at speeds of 1.57 and 3.14 rads/sec. were determined.

4) Anaerobic Power & Capacity Measures: Two distinctly different power tests were selected. Firstly, measurements of mean and peak anaerobic power were made during a 30 second Wingate test conducted on a computer interfaced modified Monarch cycle ergometer. The test protocol followed the methodology described by Bar-Or *et al.* (1977). The resistance settings were determined in accordance with the Canadian Figure Skating Association test protocol (constant x body weight in kilograms; constants: juveniles 0.065, females 0.075, males 0.085).

Secondly, lower extremity power was assessed by three trials of a stand and reach vertical jump executed from both one and two foot take-offs (measured in cm.). The difference between standing reach height and jump height was recorded and the best score for both the one and two foot take offs were used for analysis. Single legged jumps were performed on the takeoff leg used during on-ice jumping.

5. *Flexibility Measures:* A standardized sit and reach test (measured in cm.) on a Wells-Dillon device was performed to assess trunk flexion. After a standardized warm up, three trials were administered with the best result being recorded.

Statistical Analysis

Standard descriptive statistics were performed to confirm group differentiation. Due to the differing cell sizes, three separate one way analyses of variance (ANOVA) were used to evaluate mean differences between physiological variables and gender; physiological variables and maturity level; and physiological variables and technical calibre, respectively. If significant F-ratios were achieved, Newman Keuls post hoc analyses were performed to locate distinction. Pearson product moment correlations were also performed to examine the relation between selected data obtained from the individual inventories and physiological variables assessed. Data analysis was performed using Statistica (Stat Soft Inc., Release 3.1). An alpha level of 0.05 was chosen to identify statistically significant differences for all analyses.

Results & Discussion

Individual Questionnaires

1) Maturity Index: Assessment of maturational age has been suggested to be imperative in studies which investigate the effects of physical activity on performance and physiological functions (Bailey *et al.*, 1994). In the present study, self reported maturity evaluations correlated significantly with both chronological age and technical calibre of the athletes ($p \leq 0.05$). As expected, each successive calibre of skaters was chronologically older and physically more mature than the preceding group, respectively. The mean pubertal age of males and females (maturity index III) was 14 ± 1.7 years. Earlier work of Ross *et al.* (1976b) also demonstrated that both male and female figure skaters matured later than the average population.

2) Calcium Frequency Questionnaire: Whether the nutritional status of figure skaters is compromised in an effort to achieve and maintain the body image required by the sport is a critical issue, however the data from calcium questionnaires obtained in the present study did not support this concern. All subjects consumed calcium intakes equivalent to or in excess of the Canadian Recommended Nutritional Intake (RNI) requirement for their respective ages. Furthermore, the average calcium intake/day revealed no significant difference between gender or technical calibre.

3) Activity and Training Questionnaires: The training history characteristics are outlined in Table 4.3. Athletes participating in the present investigation trained consistently 10.5 months per year. Technical calibre of skater defined as juvenile, novice, junior, and senior, reported increasing frequency, duration, and intensity of training. As expected, the heightened technical demands of the higher calibre of skaters demands greater dedication to training. This trend was consistent in both the on-ice and off-ice training profiles. Competitive training commenced between the mean age of 5.8 years for juveniles and 7.7 years for seniors. This analysis revealed that skaters are starting to train competitively at a significantly younger age ($p \leq 0.05$). Beyond the commitment to the sport of figure skating, reports of participation in other sport related activities were extremely limited.

4) *Menstrual History:* Table 4.4 presents a summary of the menarcheal data obtained. Data on menstrual history was collected from 24 of the 37 female subjects. The mean age of menarche was 12.8 years. 62.5% of the menarcheal sub group reported to be regularly menstruating, as defined by 10-14 menstrual cycles per year. The remaining menarcheal females reported irregular cycles, with a minimum of 4 and maximum of 8 cycles in the last year.

Thirteen subjects were classified as pre-menarcheal. However, 61% of the pre menarcheal group were older than the mean age of menarche as defined by the meanarcheal subjects.

Physiological Fitness Evaluation

Characteristics deemed important and related to the on-ice performances of competitive figure skaters were evaluated and summarized. Table 4.5 details the mean values (± standard deviation) of all the physiological variables reported for the four technical calibres of athletes assessed.

1) Body Composition: There is evidence that physique may be a selective factor in many sports since the somatotype of champion athletes in a given sport tends to cluster as a specific body type (Hawes & Sovak, 1994). Age, height, body mass, adiposity, and BMI of the four technical calibres of skaters are presented in Table 4.5. As expected, height, body mass, and BMI was greater in males (Figure 4.1) and increased with both age and technical calibre of skater (Figure 4.2), paralleling normal growth and development of these ages. Percent body fat ranged from 8.8 ± 2.2 % to 12.5 ± 2.8 %, with senior calibre, male subjects being the leanest and the pubertal (mid teen) age females being the highest.

2) Cardiorespiratory Fitness: The 2.5 to 4.5 minute performance time of the free skating routine determined by technical calibre and gender establishes the basic aerobic dependence for energy production in the sport of figure skating. Unlike other sports, the skater cannot show fatigue because of the aesthetic requirements of the sport. Mean values reported for VO_2 max (ml/kg/min) for Canadian senior national level skaters ranged from 54.3 (females) to 64.5 (males) (Gledhill *et al.*, 1992). In the present study, VO_2 max (ml/kg/min) values ranged from 51.8 ± 3.9 to 60.7 ± 4.9 and all subjects met the criteria for VO_2 max determination (Figures 4.3, 4.4, 4.5). Once again the lowest score was obtained by the novice or pubertal (early teen age) females and the highest achieved by the male, senior calibre skaters. Although the less advanced skaters achieved scores significantly lower than the other respective groups, their mean score of 53.2 ± 5.5 ml/kg/min closely approached what has been published for the mean standard of senior national calibre (Table 4.1).

It is recognised that any relationship between a superior aerobic capacity and its requirement by the competitive figure skater must be tentative at best. It is argued that the performance demands of these athletes are primarily anaerobic in nature with minimal aerobic contribution. However, the duration of practice required to perfect the performance of the 2.0 - 4.5 minute program is clearly an aerobic activity. Therefore, it may be concluded that an elite level figure skater may not require an extremely high aerobic capacity, however the potential advantage to possessing a superior aerobic capacity would seem to be most advantageous for the individual performer. In comparison with former reports on elite figure skaters, VO_2 max values at all levels in the present study are approaching national level scores. This would appear to be a reflection of two hypotheses: (i) average cardiorespiratory fitness levels in this age group are increasing, or more likely, (ii) the increasing physical demands placed upon these athletes are eliciting elevated fitness levels.

3) Muscular Strength & Power: Muscular strength involves the application of maximum force by the skeletal muscular system at a defined velocity, whereas power is defined as the rate of performing work (speed x strength). Lower extremity strength becomes an important variable in the generation of power in this sport, as the athlete is required to accelerate and propel the body into airborne manoeuvres. The advantages of greater lower extremity strength would appear to aid in technical performance of on-ice jumping, specifically in the generation of power at takeoff and impact absorption upon landing. Although it is well documented that muscular strength increases dramatically throughout the growth period of late childhood and adolescence due to the interaction of structural, physiological, and hormonal factors, it is difficult to ascertain strength gains due to normal growth versus those due to the specific effect of training without a control group.

Strength assessments revealed that peak torque (Nm) of both left and right knee extension and flexion at speeds of 1.57 and 3.14 rads/sec. was analogous to the previous trends of significantly increasing values with advanced technical calibre, age, and sex ($p \leq 0.05$). Anaerobic peak power (watts) and relative peak power (watts/kg) determined during the Wingate test paralleled the strength differences found in these athletes. Vertical jump scores (cm) obtained from both one and two foot takeoffs also revealed a similar pattern of achievement (Figure 4.4 & Figure 4.6).

4) Flexibility: Although the importance of flexibility in figure skating has not been quantitatively established, it is deemed an important prerequisite for figure skaters for three reasons: (i) in order to achieve proper form, (ii) in the application of force, since a greater force can be generated the greater the range of muscular force application, and (iii) in prevention of injuries. Preliminary studies (Yu *et al.*, 1996) conducted on elite level, female figure skaters from the United States implied that the incidence of injuries decreased dramatically with increased flexibility and routine stretching regimes. Flexibility is a highly trainable variable and therefore these findings correlated well with both the number of hours of off-ice conditioning and ballet training. The data from the present study are similar to findings when data was analysed by sex. Significant increases in flexibility with advanced calibre was seen in both the male and female figure skaters, independently. However when genders were pooled, as illustrated in Table 4.4, it appears that flexibility decreases in the senior calibre. This is explained by the larger distribution of male subjects in this category. Although degrees of improved flexibility were apparent with advanced calibre, females were significantly more flexible than males.

Conclusions

Although physical training programs may be prescribed which will assist with developing athletes toward an optimal or desirable prototype for a specific sport, athletes can also be selected for a certain sport based upon how closely their individual profiles approximate the prototype for that sport. It may be argued that the influence of physical training on this physiological prototype is small in comparison to the range of genetic variation. It is also evident that human performance is a multivariate phenomenon; other factors such as biomechanics, psychological state, physical environment and socio-cultural context will affect performance. However, the function of the human body can be deemed an essential part of the total performance matrix. As performance at the highest level improves, the magnitude of improvement are incrementally smaller. Thus attention to the detail of all the elements in the performance matrix becomes increasingly significant.

The physiological fitness profiles of these groups of competitive figure skaters strongly appeared to be dominated by high scores in specific characteristics in which training could have exerted an important role. A comparison of the mean scores from four successive calibres of skaters provided evidence that a significant increase in scores parallels increasing age, maturation, and levels of competition within the sport. The physiological tests distinctly differentiated between sub groups of calibres with successive calibre of skaters demonstrating significantly greater scores in all tests examined. It is suggested that the increase among selected variables between groups may support the contribution of training to physiological development.

Skaters in the present study possessed distinct body types which may emphasize the hereditary determinant of their preselection of the sport. It appears that changes in the nature of competitive figure skating have given the immature, lighter, leaner athlete a competitive advantage. Female figure skaters competing at previous World Championships were characterized by average ages, heights, and weights that were younger, shorter, and leaner than their counterparts from earlier years. Lean, light bodies are easily projected and rotated while airborne. Increased emphasis on jumping ability in competitive performance has permitted younger skaters to surpass the jumping performances of the more physically mature senior skaters.

Cardiorespiratory fitness scores obtained by all levels of skaters examined closely approached or exceeded the nationally recommended values, prior to the competitive maturation of these athletes. Measures of lower extremity strength and power clearly illustrated the unique demands of the sport. On-ice jumping requires that a skater propel the body mass into the air and absorb the force of landing consistently on one leg. Low body fat content was coupled with greater lower extremity muscular strength in the senior calibre skaters, which increases the strength to mass ratio, enhances jumping ability, and aids in the skater's ability to resist impact forces. Both anaerobic power and jumping ability increased with technical calibre.

Many of the factors examined were found to be strikingly similar in males and females. The similarities of these findings for the males versus females could be merely fortuitous, however it would appear more likely considering the range of ages and the homogeneity of the group, that the following profiles could provide a basis of the physical and physiological requirements of this sport when performed at a competitive level.

Investigating and interpreting the physiques and physiology of young athletes from pre puberty to pre- adult ages is most interesting as changes are occurring rapidly and their systems are extremely responsive. However, the cross sectional nature of this investigation made it impossible to determine what physiological elements were brought into the sport versus the effects of sport specific training and the environmental influences independent of pubertal and normal growth related changes.

Although it is of practical interest for coaches to select young athletes who will have the most potential to become outstanding, it is also dangerous from an educational and skill development point of view in that the young athlete may spend years in training for one sport to finally discover that physiological alterations as a result of puberty preclude further development. This aspect of the question must be seriously considered by those working with and responsible for the young athlete. It may be however, that even given a body type projection that is unfavourable for the sport, a developing athlete may still wish to persue a competitive career in the sport.

References

Bailey, D. (1994). Invited Paper: Physical activity and the attainment of peak bone mass in children. *The Australian Journal of Science and Medicine in Sport*, 26(½):3-5.

Bailey, D., McKay, H., Faulkner, R. & Drinkwater, D. (1994). A non-invasive method for determining maturational status in adolescent boys and girls in longitudinal investigations. *Canadian Journal of Applied Physiology*, 19 (Suppl): 3P.

Bar-Or, O., Doton, R. & Inbar, O. (1977). A 30 second wingate all-out ergometric test: Its reliability and validity for anaerobic capacity. *Israel Journal of Medical Science*, 13: 326.

Gledhill, N. & Jamnik, V. (1992). Fitness test result comparisons. *Coach to Coach Magazine*, Canadian Figure Skating Association, 9(3):6-9.

Grimston, D., Engsberg, J., Kloiber, R. & Hanley, D. (1991). Bone mass, external loads and stress fracture in female runners. *International Journal of Sport Biomechanics*, 7: 293-302.

Grimston, S., Willows, N. & Hanley, D. (1993). Mechanical loading regime and its relationship to bone mineral density in children. *Medicine & Science in Sports & Exercise*, 25(11): 1203-1210.

Gordon, T., Banister, E. & Gordon, B. (1969). The caloric cost of competitive figure skating. *The Journal of Sports Medicine & Physical Fitness*, 9:98-103.

Hawes, M. & Sovak, D. (1994). Morphological prototypes, assessment and change in elite athletes. *Journal of Sport Sciences*, 12: 235-242.

Heyward, V. & Stolarczyk, L. (1996). *Applied Body Composition Assessment*. Human Kinetics Publishing, Champaign IL., 21-43.

Keys, A., Fidanza, F., Karvonen, M., Kimura, N. & Taylor, H. (1972). Indices of relative weight and obesity. *Journal of Chronic Diseases*, 25: 329-343.

Niinimaa, V., Woch, Z. & Shephard, R. (1979). Intensity of physical effort during a free figure skating program. In Erauds, J. & Gros, H., (ed.), *Science in Skiing, Skating & Hockey*, Academic Publishers, Del Mar, 74-81.

Patton, S., Pyke, F., Hahn, A., Telford, R., Tumilty, D. (1986). A physiological study of competitive figure skaters. *Skaters Sport Coach*, 10(1):30-34.

Ross, W., Brown, S., Faulkner, R., Vajda, A. & Savage, M. (1976a). Monitoring growth in young figure skaters. *Canadian Journal of Applied Sport Sciences*, 1: 163-167.

Ross, W., Brown, S., Faulkner, R. & Savage, M. (1976b). Age of menarche of elite Canadian skaters and skiers. *Canadian Journal of Applied Sport Sciences*, 1:191-193.

Ross, W., Brown, S., Yu, J. & Faulkner, R. (1977). Somatotype of Canadian figure skaters. *Journal of Sports Medicine*, 17:195-205.

Schlossberger, N., Turner, R. & Irwin, C. (1992). Validity of self-report of pubertal maturation in early adolescents. *Journal of Adolescent Health*, 13: 109-113.

Smith, A. (1996). Reduction of injuries among elite figure skaters: A 4 year longitudinal study. In Proceedings of *The International Congress on the Sports Medicine and Sports Science of Skating*, San Jose, Calif.

Tanner, J. (1962). Growth at Adolescence (2nd ed.). Oxford, Blackwell.

Thoden, J. (1991). Testing Aerobic Power. In MacDougall, J., Wenger, H. and Green, H (eds.), *Physiological Testing of the High Performance Athlete*. Human Kinetics Publishing, Champaign, IL., 107-170.

Thorvaldson, C. (1990). Exercise, hormone replacement therapy and bone mass. Unpublished Master's Thesis, University of Alberta.

Woch, Z., Niinimaa, V. & Shephard, R. (1979). Heart rate responses during free figure skating manoeuvres. *Canadian Journal of Applied Sport Science*, 4(4): 274-276.

Yu, L. (1996). Injuries of national and international competitive skaters. In Proceedings of *The International Congress on the Sports Medicine and Sports Science of Skating*, San Jose, Calif.

Yuhasz, M. S. (1974). Physical Fitness Manual. London, Ontario: University of Western Ontario.

Table 4.1 Chronological Account of Physiological Profiles Previously Conducted

Author(s), Year	Technical Calibre	Age (yrs)	Body Fat (%)	VO_2 max (ml/kg/min)	Two Foot Vertical Jump(cm)	Strength	Trunk Flexibility (cm)
Present Study	**Juvenile-Senior (n=55)**	**10 - 26**	**♂ 9.7 ♀ 11.8**	**♂ 60.0 ♀ 52.5**	**♂ 51.0 ♀ 38.9**	**↑ strength with ↑ calibre**	**♂ 35.8 ♀ 45.6**
Gledhill et al., 1992	Sr. National Team	n/a	♂ 9.2 ♀ 10.7	♂ 64.5 ♀ 54.3	♂ 56 ♀ 42	n/a	♂ 47 ♀ 50
Gledhill et al., 1991	Sr. National Team	n/a	♂ 8.6 ♀ 10.6	♂ 63.5 ♀ 54.6	♂ 55 ♀ 43	n/a	♂ 49 ♀ 49
Gledhill et al., 1975	Sr. National Team	n/a	♂ 10.1 ♀ 11.8	♂ 51.6 ♀ 50.1	♂ 57 ♀ 42	n/a	♂ 48 ♀ 47
Patton et al., 1986	n/a (n = 7)	15.5	n/a	♂ 56.7 ♀ 48.4	♂ 47.3 ♀ 36.8	n/a	n/a
Niinimaa et al., 1979	Junior & Senior (n = 9)	18 - 22	n/a	♂ 58.5 ♀ 48.9	n/a	n/a	n/a
Gordon et al., 1969	College	18	n/a	47.7	n/a	n/a	n/a

"n/a" refers to data not reported.

Table 4.2 Descriptive Characteristics of the Four Technical Calibres of Figure Skaters. Values are reported as Mean ± Standard Deviations.

Group Characteristics	Juvenile	Novice	Junior	Senior
Subject Population (n)	7	16	22	10
Height (cm)	138.4 ± 8.3	154.7 ± 7.8	164.2 ± 8.1	171.2 ± 13.7
Body Mass (kg)	32.5 ± 7.3	45.2 ± 8.1	57.0 ± 10.8	61.4 ± 10.7
Age (yr)	10.5 ± 1.5	13.4 ± 1.4	16.0 ± 1.9	21.63 ± 2.9
Maturity Index	1-2	2-3	3-4	5

Table 4.3 Training Profiles. Values are reported as Means ± Standard Deviations.

Training Profile	Juvenile	Novice	Junior	Senior
Starting Age of Competition (yrs.)	5.8 ± 1.7	7.2 ± 1.8	6.9 ± 2.2	7.70 ± 3.1
Total Years of Competitive Training (yrs.)	2.5 ± 1.8	5.3 ± 2.2	6.5 ± 2.2	13.0 ± 4.5
On-Ice Training:				
Months per Year	10.5 ± 1.8	10.5 ± 0.8	10.5 ± 1.7	11.0 ± 0.4
Days per Week	4.1 ± 1.0	5.5 ± 0.9	5.6 ± 0.8	5.7 ± 0.6
Hours per Day	1.6 ± .42	1.9 ± 0.4	2.0 ± 0.5	2.5 ± 0.3
Off-Ice Conditioning: *Stretching, Cardiorespiratory, Resistance or Strength, Plyometric/Jump Training and Dance Training (Ballet, Jazz, Tap, Theatre)*				
Hours per Week	1.0 ± 1.1	1.7 ± 1.6	3.6 ± 1.8	4.8 ± 1.4

Table 4.4 Summary of Menarcheal Data.

Menstrual Status	n	Comments
Menarcheal	24	Mean Age of Menarche 12.8 yrs 62.5% classified as regularly menstruating (10-14 cycles per year) 47.5% classified as irregular menstruating (4-8 cycles per year)
Pre Menarcheal	13	61.5 % (n = 8) were older than the mean age of menarche

Table 4.5 Physiological Fitness Evaluation Profile of Four Technical Calibres of Competitive Figure Skaters. Values are reported as Mean ± Standard Deviations.

Physiological Variables	Juvenile	Novice	Junior	Senior
Body Composition:				
Height	138.2 ± 8.3	154.9 ± 7.8	163.9 ± 8.1	170.6 ± 13.7
Weight	32.5 ± 7.3	45.6 ± 8.1	56.0 ± 10.8	62.4 ± 10.7
Body Fat (%)	10.0 ± 3.0	12.5 ± 2.8	11.7 ± 2.3	8.8 ± 2.2
BMI	17.0 ± 0.3	20.5 ± 0.3	21.1 ± 0.4	23.2 ± 0.4
Flexibility:				
Sit & Reach	42.6 ± 4.3	40.1 ± 9.6	46.9 ± 5.2	37.6 ± 10.6
Cardiorespiratory Fitness:				
VO_2 max (ml/kg/min)	53.2 ± 5.5	51.8 ± 3.9	54.4 ± 4.8	60.7 ± 4.9
(L/min)	1.7 ± 0.3	2.3 ± 0.3	3.09 ± 0.7	3.7 ± 0.7
Anaerobic Power:				
Anaerobic Peak Power (w)	225.9 ± 95.1	423.1 ± 97.8	624.1 ± 250.3	750.1 ± 181.3
Relative Peak Power (w/kg)	6.7 ± 1.3	9.3 ± 1.3	10.6 ± 2.3	12.0 ± 1.1
Vertical Jump - One Foot	21.5 ± 5.5	26.5 ± 6.6	33.4 ± 6.7	40.7 ± 10.2
Vertical Jump - Two Foot	30.3 ± 4.2	37.4 ± 6.5	45.3 ± 6.8	53.0 ± 9.0

Continued				
Isokinetic Strength:				
Dominant Leg Extension (90 deg/sec)(Nm)	74.7 ± 28.1	106.9 ± 22.0	152.0 ± 46.9	204.3 ± 67.7
Dominant Leg Extension (180 deg/sec)(Nm)	50.5 ± 18.2	78.5 ± 14.5	112.5 ± 37.2	144.7 ± 42.0
Non Dominant Leg Extension (90 deg/sec)(Nm)	72.8 ± 26.5	107.0 ± 23.8	152.2 ± 43.0	193.2 ± 61.5
Non Dominant Leg Extension (180 deg/sec)(Nm)	50.5 ± 18.2	78.5 ± 14.5	112.5 ± 37.2	144.7 ± 42.0

Significant differences were found among all physiological variables examined between all four technical calibres of skaters (juvenile, novice, junior, senior) ($p \leq 0.05$).

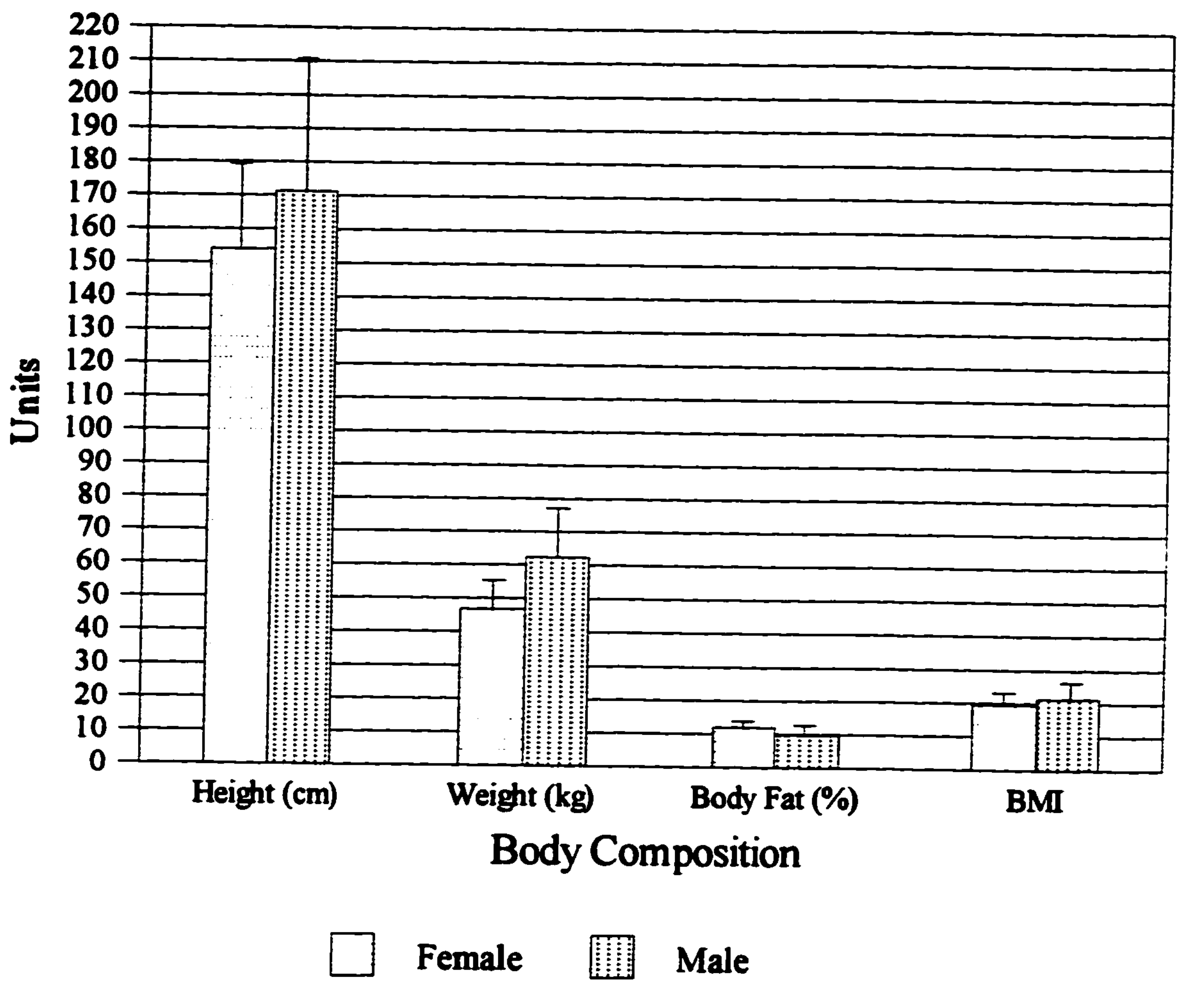


Figure 4.1 Body composition differences in male versus female competitive figure skaters. Values are reported as Mean ± Standard Error.

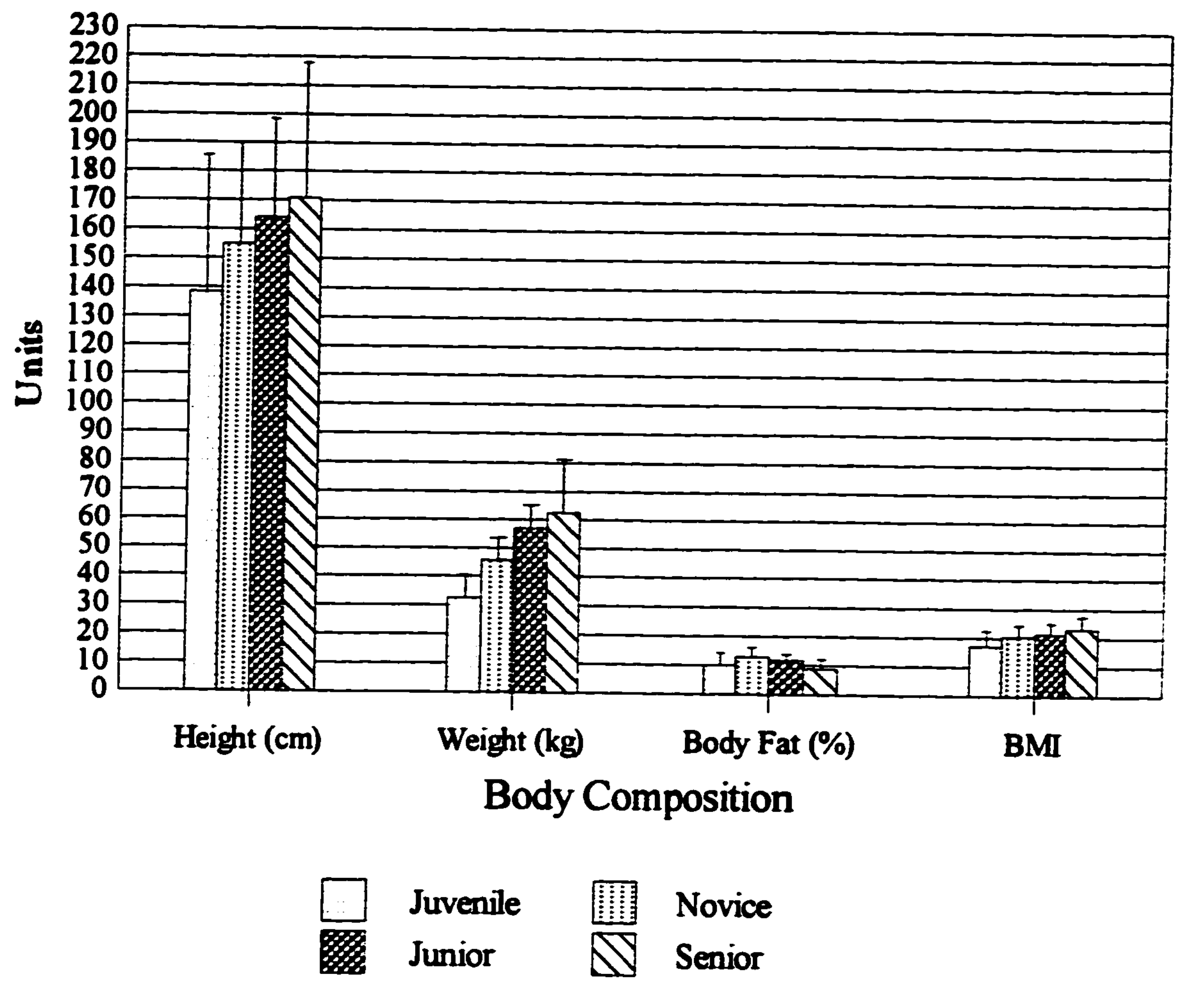


Figure 4.2 Body composition differences in four selected technical calibres of competitive figure skaters. Values are reported as Mean ± Standard Error.

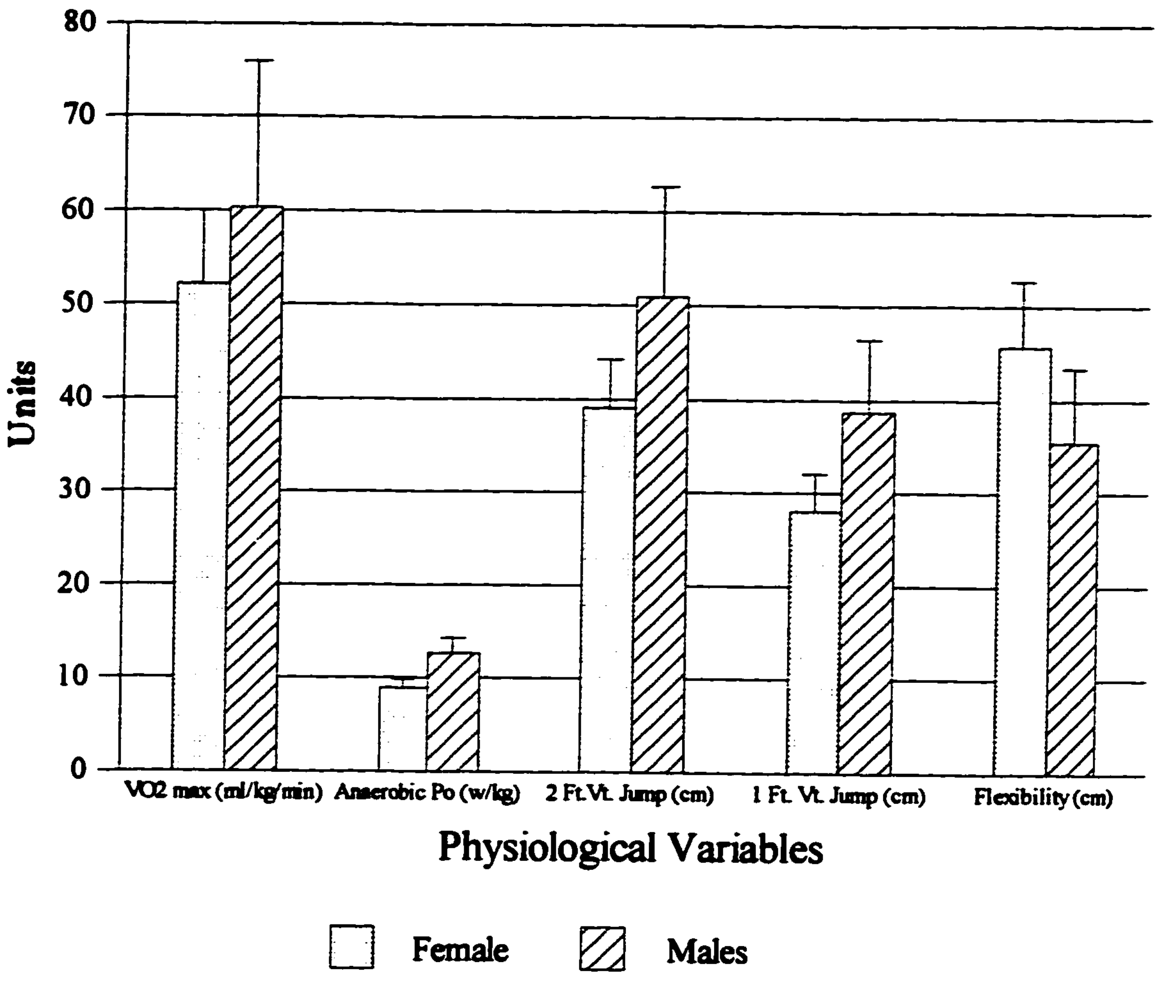


Figure 4.3 Comparisons between selected physiological variables and sex in competitive figure skaters. Values are reported as Mean ± Standard Error.

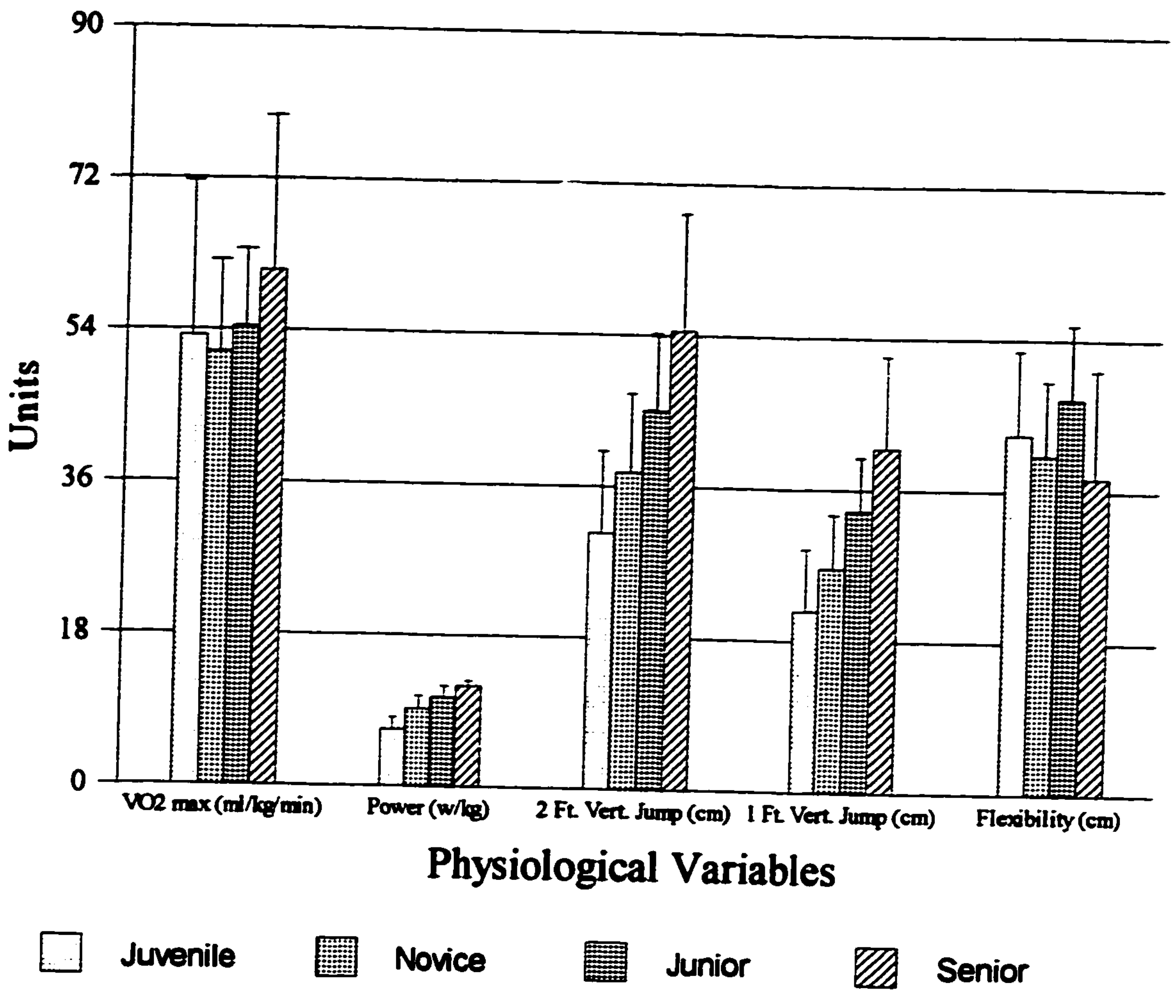


Figure 4.4 Comparisons between selected physiological variables and the four technical calibres of figure skaters examined. Values are reported as Mean ± Standard Error.

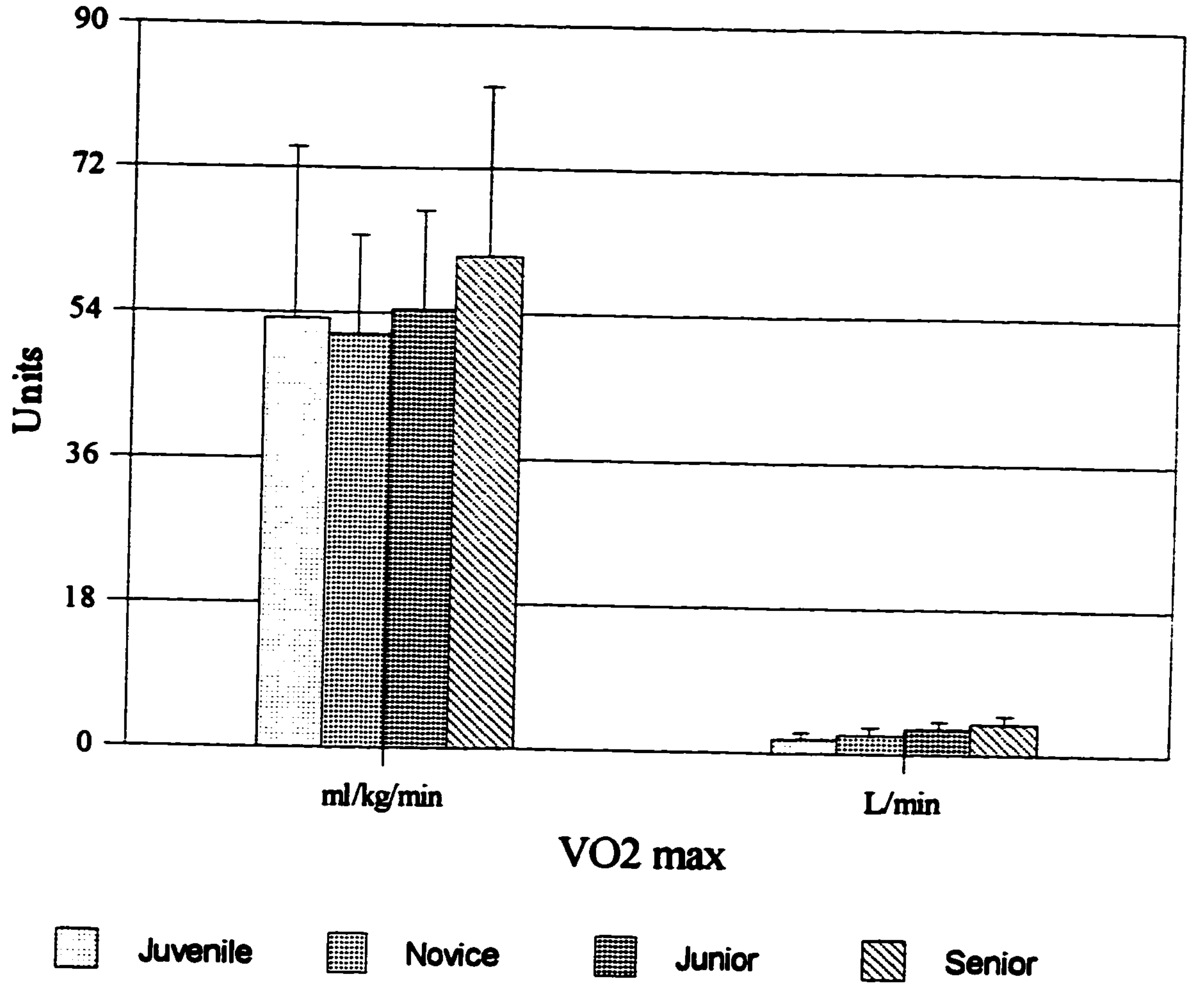


Figure 4.5 Comparisons of VO_2 max in ml/kg/min versus L/min in selected calibres of figure skaters. Values are reported as Mean ± Standard Error.

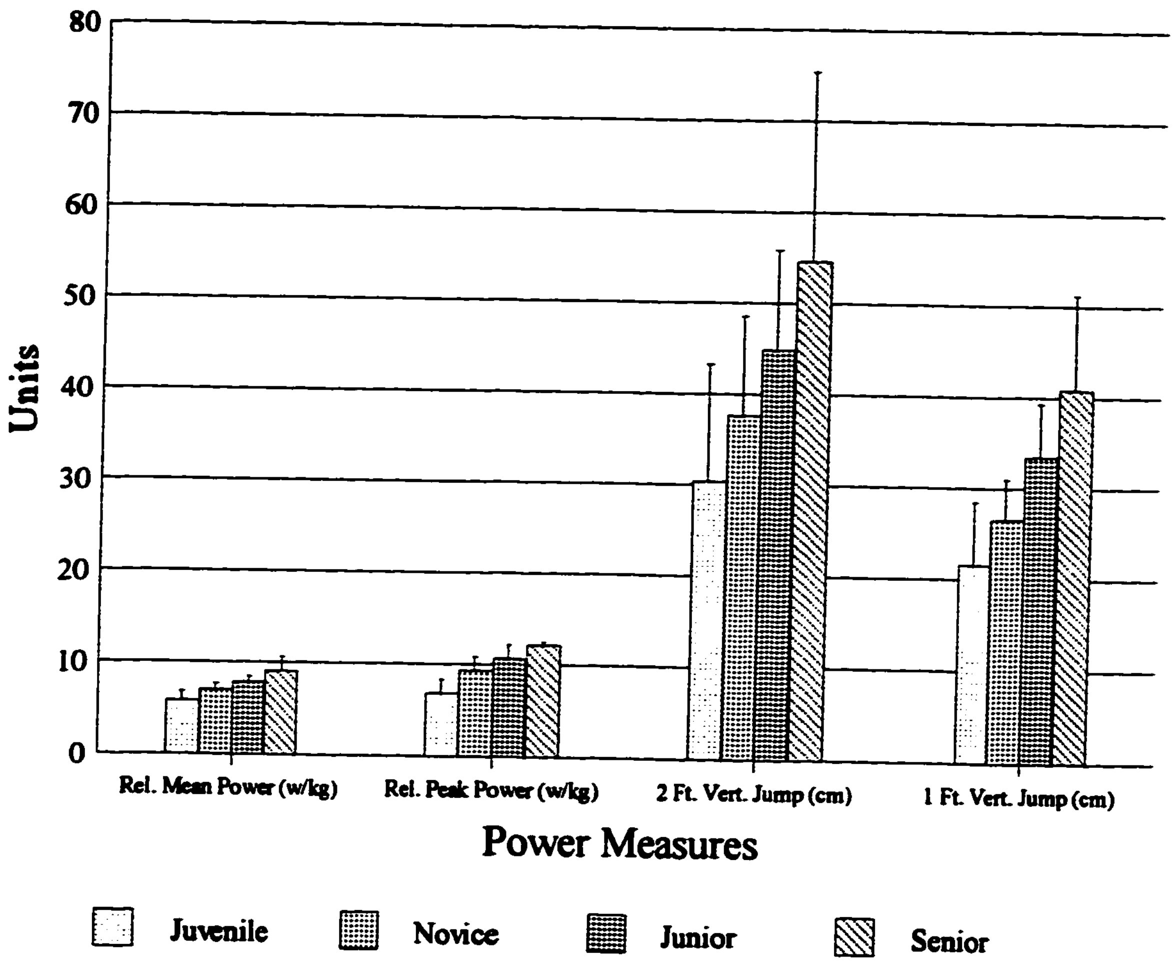


Figure 4.6 Power comparisons in selected calibres of figure skaters. Values are reported as Mean ± Standard Error.

CHAPTER FIVE

Lower Extremity Bone Mineral Density Profiles of Competitive Figure Skaters

Project I

A CONTRA LATERAL COMPARISON OF LOWER EXTREMITY BONE MINERAL DENSITY IN COMPETITIVE FIGURE SKATERS

Presented at The Integrative Biology of Exercise Conference
Vancouver, October, 1996

Project II

A COMPARISON OF LOWER EXTREMITY BONE MINERAL DENSITY OF COMPETITIVE FIGURE SKATERS TO NON TRAINED CONTROLS

A CONTRA LATERAL COMPARISON OF LOWER EXTREMITY BONE MINERAL DENSITY IN COMPETITIVE FIGURE SKATERS

Abstract

A comparison of dominant versus non-dominant lower extremity bone mineral density (BMD) was conducted to investigate the adaptive effect of sport specific impact load-type training on bone development. The study involved 55 competitive figure skaters of both genders, ranging in age from 10-26 years and technical calibre from juvenile to senior national levels. The performance of on-ice jumping requires the skater to land consistently on a single leg, absorbing the mechanical stress of the impact backwards, in a technically prescribed configuration. Based upon previous kinetic and kinematic studies (Chapter IIIa & IIIb) conducted on landing forces in figure skaters, five contra lateral comparisons were selected as the primary impact absorbing bone sites for the purpose of these analyses: left and right femoral neck, left and right Ward's triangle, left and right tibia/fibula combined and left and right tibia and fibula in isolation. BMD was quantified using dual energy x-ray absorptiometry (QDR 4500, Hologic Inc., Waltham, MA). Significantly greater ($p \leq 0.05$) BMD was found in the landing or dominant limbs at four of the five sites examined: femoral neck, Ward's triangle, tibia/fibula combined, and isolated tibia in all calibres of skaters. The higher calibre skaters exhibited the greatest differences between limbs. No significant differences were revealed in the isolated fibula. A more site specific analysis revealed that the ratio of differences calculated between BMD of landing versus non landing legs decreased from the proximal to the more distal bone regions examined. The contra lateral research design employed in this study provided the opportunity to ameliorate the collinearity problems inherent in addressing differences in bone mineral density and specifically examine the localized effect of mechanical impact loading.

Key Words: *Bone Mineral Density; Figures Skaters; Impact Loading; Landings.*

Introduction

Several researchers (Bailey *et al.*, 1996; Blimkie *et al.*, 1996; Cooper *et al.*, 1995; Faulkner *et al.*, 1993) have proposed that the potential to "bank bone" or accumulate bone mineral density (BMD) may be greatest during the growing years and failure to attain a sufficient level of bone density during these years may contribute significantly to a bone mineral deficit in later life. A number of genetic, lifestyle (eg., diet, physical activity), and hormonal (eg., gynecolgic-endocrine) factors have been implicated as important determinants in maximizing bone mass potential. Although a dose response relationship for any of these variables in isolation has yet to be defined, the effect of mechanical load-type activities has been cited as being a primary contributor (Bailey *et al.*, 1996; Chilibeck *et al.*, 1995). Despite being widely accepted, limited data are available on the effects of impact-type training on bone status in children and adolescents. Regardless of age, athletes participating in impact loaded activities are often exposed to a tremendous amount of mechanical force. The majority of research in this area has studied athletic groups in post pubertal, menopausal, or aging populations. In these populations, comparisons of bone mineral density among athletes representing several sports with different loading characteristics have been studied (Fehling *et al.*, 1995; Heinonen *et al.*, 1995; 1993; Nilsson & Westlin, 1971). These researchers have investigated the potential contribution of training regimes to BMD enhancement. It has been concluded that training programs which include high peak forces and high strain rates in versatile movements are the most effective stimuli of bone formation. In a recent review article, Chilibeck *et al.* (1995) concluded that physical activities designed to increase bone mass and strength should involve loads of high magnitude and rate, be dynamic in nature and involve varied and diverse patterns of stress. In contrast, research conducted on immobilization or unloading such as bed rest or space flight, exhibits the opposite effect (Leuken *et al.*, 1993).

More specifically, research exists that supports the site specificity of loading, as a result of dominance (Faulkner *et al.*, 1993) or sport specific training programs designed to load the specific region (Haapasalo *et al.*, 1996; Kannus *et al.*, 1994; Pirnay *et al.*, 1987). Faulkner *et al.* (1993) reported that dominance affected bone mineral density (BMD) and bone mineral content (BMC) in the upper extremities, but did not affect the weight bearing limbs of children ages 8-16 years. Studies surveying unilateral sports (Haapasalo *et al.*, 1996; Kannus *et al.*, 1994; Pirnay *et al.*, 1987) have demonstrated that site specific loading has a localized effect on BMD. Tennis has been the model sport used to investigate the effects of impact on contra lateral limbs. Table 5a.1 outlines the studies reporting significant differences found between limbs proposed as a result of sport intervention.

Figure skaters represent an important target group when studying the effects of physical activity or more specifically mechanical loading on bone for several reasons. The typical training regime of the competitive figure skater involves muscular actions producing dynamic, versatile, high magnitude, and varying rates of impact-type loading. Primarily, the activities involve a unilateral impact such as the landing of on-ice jumps, since figure skaters consistently use one leg as the landing leg for all on-ice jumps. The competitive career of figure skaters, encompassing their most intensive training, corresponds with the span signifying peak puberty and growth spurt. As stated previously, this window during childhood, maturation, and adolescence has been identified as the time when bone is the most responsive to physical load and the critical span in which bone mineral density can be best accumulated to maximal potential (Haapasalo *et al.*, 1996; Bailey *et al.*, 1996; Slemenda *et al.*, 1994; Forwood & Burr, 1993). There has only been one article published reporting BMD in figure skaters. (Slemenda & Johnston, 1993). Slemenda & Johnston (1993) compared young (mid-teen) female figure skaters aged 10-23 with non-athletic control subjects to ascertain whether there were differences in skeletal densities. Significantly higher BMD of the lower extremities was found in skaters (14.1 %), with no differences appearing in the upper extremities. These apparent differences in BMD between skaters and controls did not appear until about 15 years of age, at which time there was no further change for controls, whereas BMD continued to increase for skaters. The mechanisms proposed by these authors for the increasing skeletal densities in ice skaters included the intense, repetitious on-ice jump training and the repetitive use of the same muscle groups.

In sport related research, a commonly addressed question is whether the sport imposed the changes or whether specific, pre-determined body types excel naturally within these selected sports? Therefore, is selection bias the cause of the observed differences? It has been argued that the higher bone densities seen in athletes may allow more intensive training to be undertaken rather than being secondary to it. This suggests that this athletic population may have a predetermined bias owing to a genetic makeup that would favour athletic success. Despite the difficulty in addressing this issue, this type of investigation offers a means of exploring the relationship between physical activity and bone and provides a model to help explain possible mechanisms for enhancing bone mineral. Thus, the purpose of this study was to investigate the effects of sport specific impact-type training on the lower extremity bone mineral densities of a competitive group of pre pubescent, pubescent, and post pubescent figure skaters by means of a contra lateral research design. It was hypothesized that BMD at the impact loaded sites of the dominant lower extremity would be significantly greater than the non dominant limb.

Material and Methods

Subjects

Fifty five competitive figure skaters (37 females and 18 males) ranging in age from 10-26 years and in calibre from juvenile to a senior national level gave informed consent to participate in this study (Appendix J). The testing procedures were approved by both the Faculty of Physical Education & Recreation and Hospital Radiation Safety Ethics Committees at the University of Alberta.

Physiological Profiles & Individual Questionnaires

All subjects completed a physiological fitness evaluation and a series of four individual questionnaires selected to provide background data and to qualitatively profile group characteristics of the four calibres of skaters studied. The physiological fitness evaluation consisted of: (i) body composition (height, weight, and an estimation of adiposity), (ii) cardiorespiratory fitness ($\dot{V}O_2$ max), (iii) anaerobic power (30 second wingate), (iv) lower extremity muscle strength (Biodex measures of leg flexion and extension), and (v) trunk flexibility. The questionnaires included a (i) Self Reported Maturity Index, (ii) Dietary Calcium Frequency Analysis, (iii) Training and Activity

Inventory, and (iv) Menstrual History (females only) (Appendices F-I). Complete analyses of baseline physiological fitness data and questionnaires are described in chapter IV of this thesis. Lower extremity dominance was dictated by the landing leg used by the skater in executing on-ice jumps. All participants in the study were classified as being injury free, with no history of bone disease and not taking any medication known to affect bone metabolism.

Bone Mineral Density Procedures

BMD was quantified using dual energy x-ray absorptiometry (QDR 4500, Hologic Inc., Waltham, MA) in fan beam mode, at the Garneau Bone Laboratory, Edmonton, Alberta. Quality control for bone measures was assured by scanning a lumbar spine phantom of known mineral content each day prior to testing. Coefficients of variation (CV) and rate of change per year (RC) were calculated over a six month period, encompassing the testing months for bone mineral content (BMC), bone mineral density (BMD), and area of the lumbar spine phantom (Table 5a.2). All scans were conducted within a two month period, and performed and analysed by the same skilled technician. Subjects were scanned wearing non restrictive clothing and free of all metal objects. Subjects were positioned on the scanning table for each respective scan and lightly secured to eliminate movement during scanning as described below.

Scanned Regions: Five contra lateral sites were selected as impact absorbing bone locations for comparison: left and right femoral neck, left and right Ward's triangle, left and right tibia/fibula combined and left and right tibia and fibula isolated. The tibia/fibula data were further subdivided into proximal, mid, and distal thirds for more detailed site specific comparisons. Scanning positions as shown in Figure 5a.1 and Figure 5a.2, and reprints of scans as illustrated in Figure 5a.3 and Figure 5a.4 are described as follows:

(i) femoral neck and Ward's triangle: The subject was supine and centred within the longitudinal whole body lines outlined on the scan mat. Hands were placed prone and equidistant from the torso on either side of the body. Feet were lightly secured by a plastic form to replicate position angle between subjects and eliminate movement. For contra lateral views of the femoral neck and Ward's triangle, left and right subsequent scans were performed without repositioning the body (Figure 5a.1 and Figure 5a.3).

(ii) Tibia/fibula combined & isolated: Subjects were seated on the scanning table with legs extended. The feet were pronated slightly to rotate the position of the tibia/fibula so that both could be seen clearly in the view without obstruction (Figure 5a.2).

(iii) Tib/fib (⅓), tib/fib (mid), tib/fib (distal): From the tibia/fibula scans, calculations were made to analyse specific sections of the tibia and fibula which corresponded to the height and the support of the skate. Initially, a measurement was taken from the lateral epicondyle to the lateral malleolus of each respective leg. The half way point was determined and subsequently divided into thirds: tib/fib (⅓), tib/fib (mid), tib/fib (distal). Each section corresponded to a specific bone region of interest: tib/fib (⅓) - above the skate, tib/fib (mid) - boot top, and tib/fib (distal) - below the boot top (Figure 5a.4).

Statistical Analysis

Standard descriptive statistics were performed to define group differentiation. Due to the differing cell sizes, three separate one way analyses of variance (ANOVA) were used to evaluate mean differences between BMD and gender; BMD and maturity level;

and BMD and technical calibre, respectively. An alpha level of 0.05 was chosen to identify statistically significant differences among groups. If significance was achieved, Newman Keuls post hoc analyses were performed to locate distinction. In addition, a ratio of difference was calculated between groups to estimate the magnitude of the possible effect. Data analyses were performed using Statistica (Stat Soft Inc., Release 3.1).

Results

Descriptive group characteristics according to the technical calibre of the skaters are presented in Table 5a.3. An analysis of the physiological data revealed that the profiles of each of the respective calibre of skaters were significantly different. The more technically advanced skaters achieved higher overall fitness scores than the less advanced groups. As expected, age and maturation paralleled the technical development of the athletes. Differences in training frequency, intensity, and duration as reported in the training inventory also paralleled the technical development of the athletes. Training regimes of the senior calibre skaters were classified as longer in duration, more frequent, and of greater intensity than the less advanced skaters as outlined by the training profile in Table 5a.4.

In agreement with the literature of this circum pubertal population, BMD at all selected bone sites increased with both chronological age and maturity. A significant effect of gender was seen at all respective ages and maturation levels, with males significantly higher than females in all groups (Figure 5a.5). In contrast to the literature representing a non trained population, significant differences were found between dominant and non dominant limbs of the lower extremities. Table 5a.5 outlines the mean contra lateral values of BMD and the percentage of contra lateral difference at the five sites examined. Significantly greater ($p \leq 0.05$) BMD's were found in all calibres of skaters, in the dominant limbs at four of the five sites examined: femoral neck, Ward's triangle, tibia/fibula combined, and tibia isolated, with the higher calibre skaters exhibiting the greatest differences between limbs (Figure 5a.6 and Figure 5a.7). The effect of dominance did not achieve significance in the fibula isolated.

Sectioning the tibia/fibula data to correspond to boot height also revealed differences between dominant and non dominant limbs at the proximal, mid, and distal sections (Figure 5a.8). Of particular interest was the pattern of a decreasing ratio of difference between limbs from proximal to the most distal bone sites examined (Table 5a.5).

Discussion

This study investigated the site specificity of mechanical load on BMD in a high impact, repetitive load-type of training. The main findings revealed significant differences between the BMD of the landing versus the non landing lower extremity limbs. This may suggest that the influence of the training for the sport of figure skating at a competitive level has a side to side affect on BMD. All athletes under investigation commenced their competitive career prior to menarche and trained a mean of 10.7 months per year, 9.2 hours of on-ice training and 3.0 hours of off-ice training per week. The differences observed between the BMD of dominant and non dominant limbs may be partially explained by the commitment to a consistent training technique. On-ice jumping requires the skaters to consistently land and absorb landing impact on the same dominant leg. Peak strain magnitude has been cited as the predominant strain variable capable of producing an osteogenic stimulus with rate and distribution of strain within the skeletal system adding important factors. Any change in movement conditions influencing the kinematics and kinetics of the movement affects the mechanical stress and in turn affects the bone. Earlier work conducted as described in Chapter IIIa, revealed that peak impact forces increased from 3 to 9 times the skaters' respective body weight, with the greatest site of impact being absorbed by the femoral neck and lumbar spine upon landing of single, double, and triple revolution jumps. A kinematic analysis (Chapter IIIb) also suggested that maximal joint flexion occurred at the hip upon landing. The skate appeared to inhibit ankle flexion and to a lesser degree knee flexion. Therefore, summation of all lower extremity joints could not be used to evenly and safely absorb the vertical impact force imposed upon the skater during the landing phase of the jump. These findings correspond with the differences found between dominant and non dominant BMD at specific locations of the lower extremity. The other characteristics of training in the sport of figure skating (eg., consistently being weight bearing, repetitious use of the same muscle groups, bounding or hopping from leg to leg) could also contribute to the significant difference between the dominant and non dominant limbs of this athletic population and also their uniqueness in comparison to the reference population as outlined in a subsequent paper.

The results of the present study support the earlier work of Slemenda *et al.* (1994) who found that when bone is mechanically loaded there is a response that occurs at that specific site. The theory of minimum effective strain stimulus (MESS) as proposed first by Frost (1973) states that a threshold of mechanical loading must be met to evoke an increased level of BMD. It is speculated that the impact forces absorbed during the execution of on-ice jumping may be of threshold value, particularly at the designated sites (eg., femoral neck and Ward's triangle of the dominant limb). Mechanical forces absorbed by the non dominant limb or at the more distal sites may not have been of sufficient magnitude to allow for enhanced BMD. A more recent theory has been proposed by Heinonen *et al.* (1995) claiming that a "steal phenomenon" exists. This theory suggested that a redistribution of bone mineral occurs from non loaded to loaded sites. Other investigators have cited the same occurrence in response to the demand of bone formation, however it has not been clearly defined as to whether it is true redistribution or additional accumulation as a result of MESS. Regardless, this phenomenon has been demonstrated in both the upper and lower extremities of trained individuals. Table 5a.1 presents a comparison of: 1) the present lower extremity findings, 2) previous contra lateral upper extremity BMD studies in sport, and 3) a non active childhood and adolescent population.

Previous studies have indicated that sex differences in BMD appear primarily around puberty in a non-trained population (Faulkner *et al.*, 1996; Slemenda *et al.*, 1994; Glastre *et al.*, 1990). In these analyses, the mean BMD values of males were significantly greater than females. Significant differences were found between dominant and non dominant limbs of all ages investigated, representing pre pubertal, pubertal, and post pubertal populations. In other unilateral studies designed to investigate the influence of starting age and maturation on BMD (Kannus *et al.*, 1995), athletes commencing activity prior to maturation accumulated greater peak bone mass at a given age than those who started their competitive career after menarche. In the present study all subjects commenced competitive training between the ages of 5.8 and 7.7 years. An earlier study conducted by Niinima *et al.* (1979) reported a mean starting age of 8.1 ± 1.3 years. This would suggest that in the past decade, figure skaters are commencing serious competitive training at younger ages.

Of significance to these analyses was that the ratio of differences in lower leg BMD paralleled the technical calibre of the athletes. The older athletes who have trained longer and achieved a higher level of technical competence, exhibited greater differences between dominant and non dominant BMD at the prime impact absorbing sites (femoral neck and Ward's triangle). As hypothesized, it was proposed that these differences were a direct reflection of imposed impact activity. As stated by Bassey & Ramsdale (1994), the specific effect at the femoral site may be explained by two sources of locally increased functional strain: (i) the ground reaction on landing transmits a compressive force to the weight-bearing skeleton, and (ii) the muscles, which extend the hip and knee during jumping have attachments at the trochanter, produce tensile forces. Both these forces may contribute to the side to side differences found in BMD.

In comparison, the effect of dominance in a non athletic population as investigated by Faulkner *et al.* (1993) found significant differences at the upper extremity sites only. It was suggested by these authors that upper extremity differences in BMD were primarily a reflection of increased tensile loading of the dominant arm. Whereas, non significant differences in the lower extremities were due to an even distribution of stress from weight bearing and unless a child has been involved in high intensity training for a very specific activity, it is unlikely that any significant bias would be observed.

An inherent problem in cross sectional studies has been the possibility of self selection of subjects. However, the side to side differences in contra lateral studies appear to be significantly greater in athletes than in the reference populations (Heinonen *et al.*, 1995). Therefore, it may be concluded that the observed differences may be due to training programs and not heredity or other external influencing or confounding factors.

Conclusions

The present study examined the role of impact as a determinant of BMD in figure skaters controlling for the effects of age, gender, maturation, nutrition and genetics, by analysing side to side differences within a single subject. BMD at selected locations were studied to determine the affect of impact and site specificity of mechanical loading. The results revealed significant differences between the landing and non landing leg's bone mineral at four of the five sites examined. Independent of age, maturation, genetics and nutrition, the bone mineral densities of the landing versus the non landing lower extremities responded differently. The largest side to side difference appeared at the femoral neck and mean differences decreased at the more distal sites. Furthermore, the affect of mechanical load was minimized at the most distal sites where the structure of the skate supports and protects the lower extremity, similar to a cast-like formation. These results support the hypothesis stating that changes in BMD are specifically induced both by mechanical loading and immobilization.

These findings support previous kinetic (Chapter IIIa) and kinematic (Chapter IIIb) analyses which suggested that the hip joint was the primary site of both impact absorption and joint flexion. Although the entire lower extremity is being mechanically loaded, it is suggested that the skate acts to dissipate the impact forces upon landing and inhibit the affects of loading on BMD at the most distal sites.

In conclusion, unilateral loading had a clearly positive effect on BMD of the dominant limb. The results of this study concluded that athletes participating in high impact activity not only had higher BMD than a normative reference, the site of impact absorption revealed the greatest effect. In addition, equipment commonly used in sport either to protect or facilitate sport performance may have differential effects on bone mineral density. These findings supported the concept of loading on bone and further illustrate the concept of specificity of the site loaded. A question that still needs to be addressed is whether the magnitude of benefit for the dominant extremity is clinically important when estimating that BMD of the one leg is a number of years ahead of its less active counterpart in the prevention of osteoporosis.

References

Bailey, D., Faulkner, R. & McKay, H. (1996). Growth, physical activity, and bone mineral acquisition. In J. Holloszy (ed.), *Exercise & Sport Science Reviews*, 24:233-266.

Bassey, E. & Ramsdale, S. (1994). Increase in femoral bone desnity in young women following high-impact exercise. *Osteoporosis International*, 4: 72-75.

Blimkie, C., Chilibeck, P. & Davison, K. (1996). Bone mineralization patterns: Reproductive endocrine, calcium, and physical activity influences during the life span. In O. Bar-Or, D. R. Lamb and P. M. Clarkson (ed.), *Perspectives in Exercise Science and Sports Medicine*, Vol. 9, Exercise and the female: A life span approach, Cooper Publishing Group.

Chilibeck, P., Sale, D. & Webber, C. (1995). Exercise and bone mineral density. *Sport Medicine*, 19(2): 103-122.

Cooper, C., Cawley, M., Bhalla, A., Egger, P., Ring, F., Morton, L. & Barker, D. (1995). Childhood growth, physical activity and peak bone mass in women. *Journal of Bone and Mineral Research*, 10(6): 940-947.

Faulkner, R., Bailey, D., Drinkwater, D., Wilkinson, A., Houston, C. & McKay, H. (1993). Regional and total body bone mineral content, bone mineral density, and total body tissue composition in children 8-16 years of age. *Calcified Tissue International*, 53: 7-12.

Fehling, P., Alekel, L., Clasey, J., Rector, A. & Stillman, R. (1995). A comparison of bone mineral densities among female athletes in impact loading and active loading sports. *Bone*, 17(3): 205-210.

Forwood, M. & Burr, D. (1993). Physical activity and bone mass: exercises in futility? *Bone and Mineral*, 21: 89-112.

Frost, H. (1973). Bone modelling and Skeletal Modelling Errors. Charles C. Thomas Publishing, Illinois.

Glastre, C., Braillon, P., David, L., Cochat, P., Meunier, P. & Delmas, P. (1990). Measurement of bone mineral content of the lumbar spine by dual energy X-ray absorptiometry in normal children: Correlations with growth parameters. *Journal of Clinical Endocrinology and Metabolism*, 70: 1330-1333.

Haapasalo, H., Sievanen, H., Kannus, P., Heinonen, A., Oja, P. & Vuori, I. (1996). Dimensions and estimated characteristics of the humerus after long term tennis loading. *Journal of Bone and Mineral Research*, 11(6): 864-872.

Heinonen, A., Oja, P., Kannus, P., Sievanen, H., Manttari, A. & Vuori, I. (1993). Bone mineral density of female athletes in different sports. *Bone & Mineral*, 2: 1-14.

Heinonen, A., Oha, P., Kannus, P., Sievanen, H., Haapasalo, H., Manttari, A. & Vuori, I. (1995). Bone mineral density in female athletes representing sports with different loading characteristics of the skeleton. *Bone*, 17(3): 197-203.

Kannus, P., Sievanen, H., Oja, P. & Vuori, I. (1994). The site specific effects of long-term unilateral activity on bone mineral density and content. *Bone*, 15(3): 279-284.

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

Leuken, S., Arnaus, S., Taylor, A. & Baylink, D. (1993). Changes in markers of bone formation and resorption in a bed rest model of weightlessness. *Journal of Bone and Mineral Research*, 8(12): 1433-1438.

Nilsson, B. & Westlin, N., (1971). Bone density in athletes. *Clinical Orthopaedics and Related Research*, 77:180-182.

Niinima, V., Woch, Z. & Shephard, R. (1979). Intensity of physical effort during a free figure skating program. In Erauds, J. & Gros, H., (ed.), *Science in Skiing, Skating & Hockey*, Academic Publishers, Del Mar, 74-81.

Pirnay, F., Bodeux, M., Crielaard, J. & Franchimont, P. (1987). Bone mineral content and physical activity. *International Journal of Sports Medicine*, 8: 331-335.

Slemenda, C. & Johnston, D. (1993). High intensity activities in young women; site specific bone mass effects among female figure skaters. *Bone and Mineral*, 20: 125-132.

Slemenda, C., Reister, T., Hui, S., Miller, J., Christian, J. & Johnston, C. (1994). Influences on skeletal mineralization in children and adolescents: Evidence for varying effects of sexual maturation and physical activity.*Journal of Pediatrics*, 125: 201-207.

Table 5a.1 Contra Lateral BMD Studies in Sport versus a Normative Pediatric and Adolescent Population

Author(s), Year	Sport	Scan	Limb	Significant Effects
Haapasalo et al., 1996	Tennis	Norland DXA	Upper Extremity	Humeral BMC 7.6 - 25.2% ↑ Humeral BMD 5.8 - 22.5% ↑ Greater differences observed in players who commenced training during childhood (11.7 - 45.2%)
Kannus et al., 1994	Tennis	Norland DXA	Upper Extremity	Humeral BMC 28.7% ↑ Humeral BMD 25.4% ↑ Ulnar BMC 7.5% ↑ Ulnar BMD 3.1% ↑ Mean Control Difference 3%
Pirnay et al., 1987	Tennis	NOVA DPA	Upper Extremity	Radial BMD 12% ↑
Faulkner et al., 1993	Control	Hologic DXA	Upper Extremity	BMD, BMC, & BFLT significantly greater in dominant of upper extremity
			Lower Extremity	No Significant Difference

Table 5a.2 Quality Control Parameters (n = 109 scans)

Lumbar Spine Phantom	**BMD (grams/cm²)**	**BMC (grams)**	**AREA (sq/cm³)**
Mean ($\bar{x}$) ± Standard Deviation	1.04 ± 0.0	55.51 ± 0.2	53.24 ± 0.2
Coefficients of Variation (%)	0.35	0.52	0.40
Rate of Change per Annum (± %)	0.55	0.13	0.63

Table 5a.3 Descriptive Characteristics of the Four Technical Calibres of Figure Skaters. Values are reported as Mean ± Standard Deviations.

Group Characteristics	Juvenile	Novice	Junior	Senior
Personal Profile: (n)	7	16	22	10
Height (cm)	138.4 ± 8.3	154.7 ± 7.8	164.2 ± 8.1	171.2 ± 13.7
Weight (kg)	32.5 ± 7.3	45.2 ± 8.1	57.0 ± 10.8	61.4 ± 10.7
Age at Test (yr)	10.5 ± 1.5	13.4 ± 1.4	16.0 ± 1.9	21.6 ± 2.9
Maturity Index	1-2	2-3	3-4	5

Table 5a.4 Training Profiles. Values are reported as Means ± Standard Deviations.

Training Profile	Juvenile	Novice	Junior	Senior
Starting Age of Competitive Training (yrs.)	5.8 ± 1.7	7.20 ± 1.8	6.9 ± 2.2	7.70 ± 3.1
Total Years of Competitive Training (yrs.)	2.5 ± 1.8	5.3 ± 2.2	6.5 ± 2.2	13 ± 4.5
Freeskate Training:				
Months per Year	10.5 ± 1.8	10.5 ± 0.8	10.5 ± 1.3	11.05 ± 0.4
Days per Week	4.1 ± 1.0	5.5 ± 0.9	5.6 ± 0.8	5.7 ± 0.6
Hours per Day	1.6 ± 0.4	1.9 ± 0.4	2 ± 0.5	2.5 ± 0.3
Off-Ice Conditioning: *Stretching, Cardiorespiratory, Resistance or Strength, Plyometric/Jump Training and Dance Training*				
Hours per week	1.0 ± 1.1	1.7 ± 1.6	3.6 ± 1.8	4.8 ± 1.4

Table 5a.5 BMD of Dominant versus Non Dominant Lower Extremity Sites in Female versus Male Competitive Figure Skaters. Values are reported as Means ± Standard Deviations.

BMD (g/cm^2)	Female			Male		
	Dominant	Non Dominant	Ratio of Difference (%)	Dominant	Non Dominant	Ratio of Difference (%)
Femoral Neck	1.01 ± 0.18	0.98 ± 0.17	3	1.18 ± 0.18	1.12 ± 0.15	6
Wards Triangle	0.91 ± 0.20	0.88 ± 0.19	4	1.03 ± 0.17	0.97 ± 0.17	6
Tibia/Fibula	0.89 ± 0.14	0.86 ± 0.13	4	1.00 ± 0.16	0.99 ± 0.16	1
Tibia	0.97 ± 0.16	0.94 ± 0.15	3	1.08 ± 0.19	1.06 ± 0.18	2
Fibula	0.70 ± 0.11	0.70 ± 0.10	0	0.80 ± 0.11	0.79 ± 0.14	1

Table 5a.6 BMD of Dominant versus Non Dominant Lower Extremity Sites in Four Technical Calibres of Competitive Figure Skaters. Values are reported as Means ± Standard Deviations.

BMD(g/cm^2)	Juvenile	Novice	Junior	Senior
Dominant Femoral Neck	0.75 ± 0.11	0.97 ± 0.13	1.12 ± 0.10	1.29 ± 0.13
Non Dominant Femoral Neck	0.72 ± 0.11	0.94 ± 0.13	1.09 ± 0.09	1.19 ± 0.12
Ratio of Difference (%)	4	4	4	8
Dominant Wards Triangle	0.64 ± 0.08	0.88 ± 0.13	1.01 ± 0.16	1.12 ± 0.12
Non Dominant Wards Triangle	0.62 ± 0.09	0.87 ± 0.14	0.96 ± 0.17	1.03 ± 0.16
Ratio of Difference (%)	4	1	5	9
Dominant Tibia/Fibula combined	0.69 ± 0.09	0.86 ± 0.12	0.97 ± 0.10	1.07 ± 0.11
Non Dominant Tibia/Fibula combined	0.68 ± 0.08	0.84 ± 0.12	0.94 ± 0.09	1.05 ± 0.13
Ratio of Difference (%)	2	3	4	2
Dominant Tibia	0.76 ± 0.11	0.93 ± 0.14	1.05 ± 0.12	1.19 ± 0.13
Non Dominant Tibia	0.73 ± 0.08	0.91 ± 0.14	1.01 ± 0.10	1.17 ± 0.14
Ratio of Difference (%)	4	2	4	2
Dominant Fibula	0.55 ± 0.07	0.69 ± 0.10	0.78 ± 0.08	0.79 ± 0.10
Non Dominant Fibula	0.55 ± 0.09	0.69 ± 0.10	0.78 ± 0.08	0.80 ± 0.14
Ratio of Difference (%)	0	0	0	1

Table 5a.7 BMD of Dominant versus Non Dominant Boot Related Bone Regions in Four Technical Calibres of Figure Skaters. Values are reported as Means ± Standard Deviations

BMD (g/cm²)	Juvenile	Novice	Junior	Senior
Dominant Tibia/Fibula (⅓)	0.79 ± 0.13	0.99 ± 0.13	1.11 ± 0.11	1.22 ± 0.10
Non Dominant Tibia/Fibula (⅓)	0.77 ± 0.09	0.98 ± 0.13	1.09 ± 0.10	1.22 ± 0.21
Ratio of Difference (%)	3	2	2	0
Dominant Tibia/Fibula Mid	0.72 ± 1.06	0.88 ± 0.13	1.00 ± 0.11	1.09 ± 0.13
Non Dominant Tibia/Fibula Mid	0.70 ± 0.10	0.87 ± 0.12	0.97 ± 0.10	1.06 ± 0.12
Ratio of Difference (%)	2	2	3	3
Dominant Tibia/Fibula Distal	0.59 ± 0.06	0.74 ± 0.12	0.84 ± 0.10	0.94 ± 0.10
Non Dominant Tibia/Fibula Distal	0.57 ± 0.06	0.72 ± 0.12	0.81 ± 0.08	0.91 ± 0.11
Ratio of Difference (%)	3	3	4	3
Dominant Tibia (⅓)	0.94 ± 0.18	1.14 ± 0.15	1.27 ± 0.14	1.45 ± .157
Non Dominant Tibia (⅓)	0.90 ± 0.12	1.13 ± 0.15	1.24 ± 0.13	1.45 ± .231
Ratio of Difference (%)	3	1	3	0
Dominant Tibia Mid	0.78 ± 0.12	0.95 ± 0.14	1.07 ± 0.13	1.21 ± 0.15
Non Dominant Tibia Mid	0.76 ± 0.10	0.93 ± 0.14	1.04 ± 0.11	1.18 ± 0.14
Ratio of Difference (%)	3	5	3	3
Dominant Tibia Distal	0.62 ± 0.07	0.78 ± 0.13	0.89 ± 0.11	0.99 ± 0.11
Non Dominant Tibia Distal	0.60 ± 0.05	0.75 ± 0.13	0.84 ± 0.09	0.96 ± 0.11
Ratio of Difference (%)	3	4	5	3
Dominant Fibula (⅓)	0.55 ± 0.07	0.72 ± 0.10	0.77 ± 0.09	0.76 ± 0.09
Non Dominant Fibula (⅓)	0.56 ± 0.07	0.72 ± 0.10	0.77 ± .086	0.79 ± 0.23
Ratio of Difference (%)	0	0	0	4
Dominant Fibula Mid	0.59 ± 0.09	0.74 ± 0.11	.82 ± 0.10	0.83 ± 0.13
Non Dominant Fibula Mid	0.59 ± 0.11	0.74 ± 0.10	.82 ± 0.10	0.81 ± 0.13
Ratio of Difference (%)	0	0	0	2
Dominant Fibula Distal	0.50 ± 0.06	0.62 ± 0.12	0.72 ± 0.10	0.80 ± 0.10
Dominant Fibula Distal	0.50 ± 0.09	0.62 ± 0.10	0.71 ± 0.09	0.76 ± 0.12
Ratio of Difference (%)	0	0	1	5

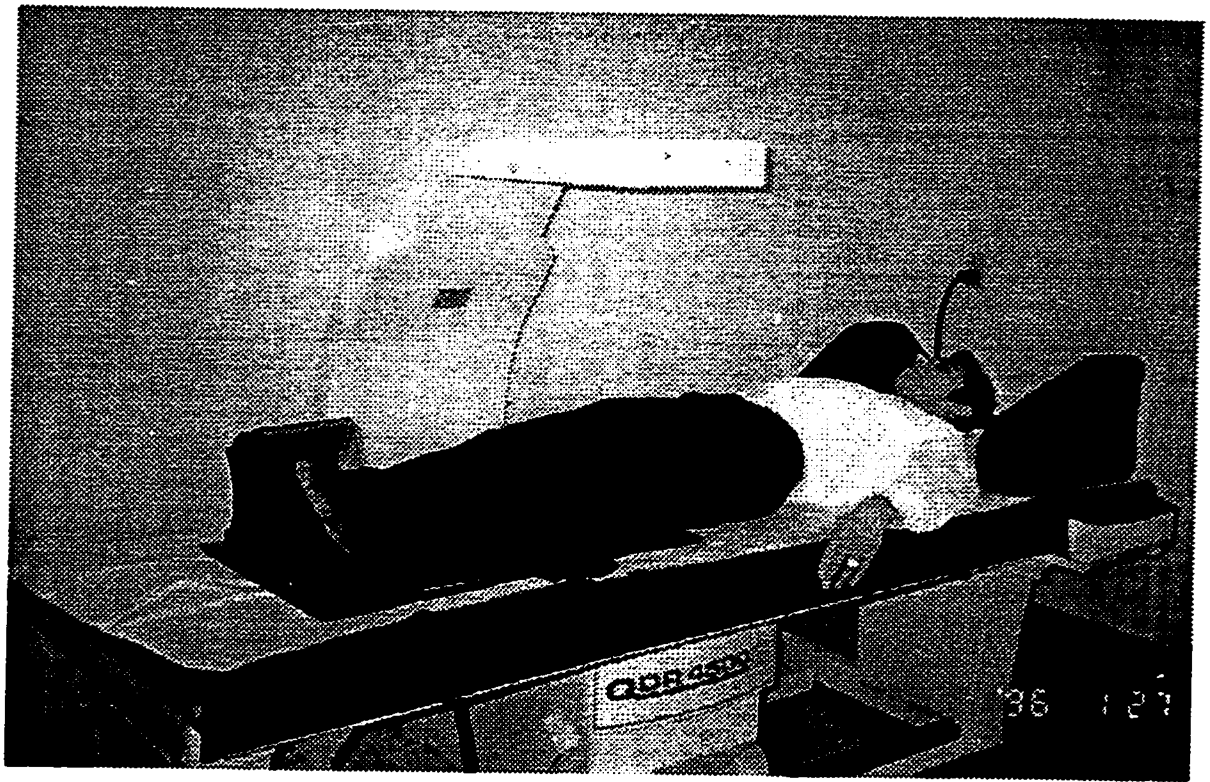


Figure 5a.1 QDR 4500 Hologic Scanner: Supine scanning position.

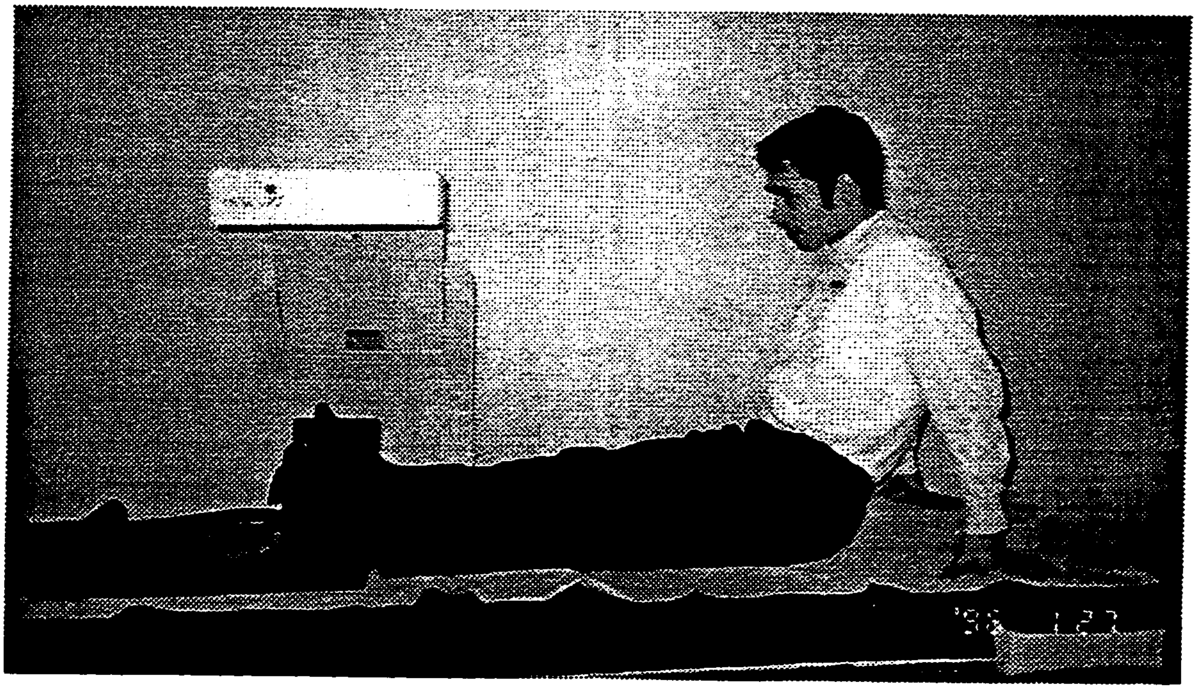


Figure 5a.2 QDR Hologic 4500 Scanner: Seated scanning position.

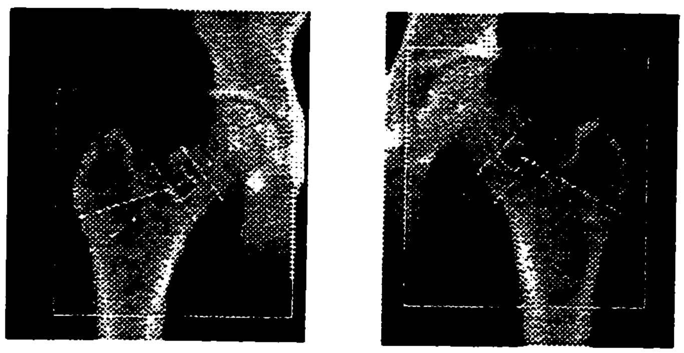


Figure 5a.3 Scanned reprints of left and right femoral neck. Calculations of left and right Ward's triangle.

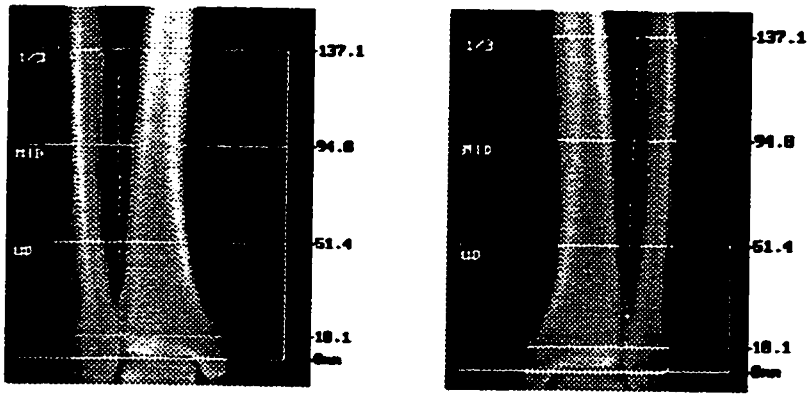


Figure 5a.4 Scanned regions of the right and left tibia/fibula combined, right and left tibia isolated, and right and left fibula isolated. Boot height corresponding sections are labelled as: ⅓ - above the boot, mid - boot top, UD (ultra distal) - below the boot top.

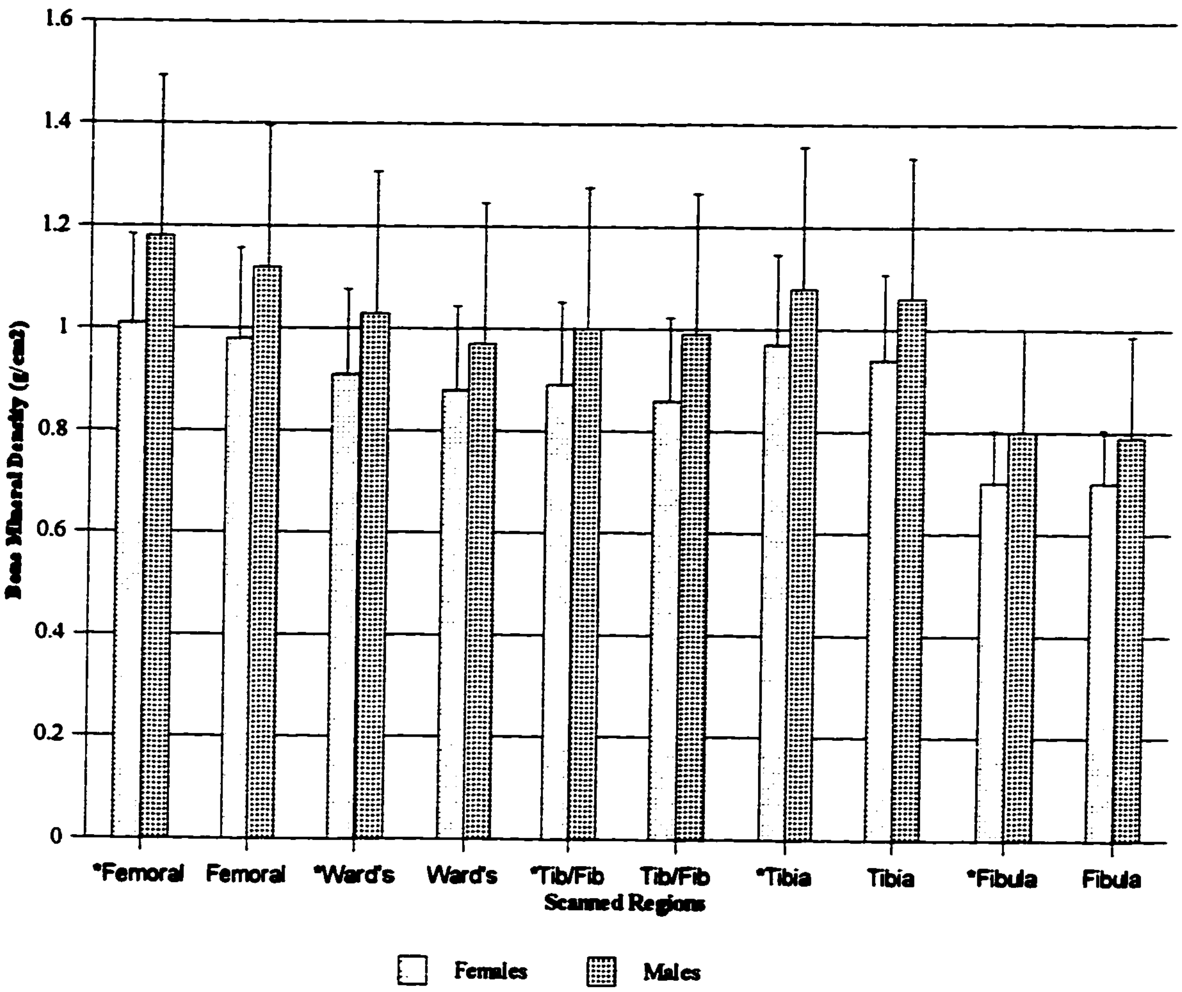


Figure 5a.5 Bone mineral density (BMD) at selected lower extremity sites. Values are reported as Mean ± Standard Error.

* Represents dominant limb

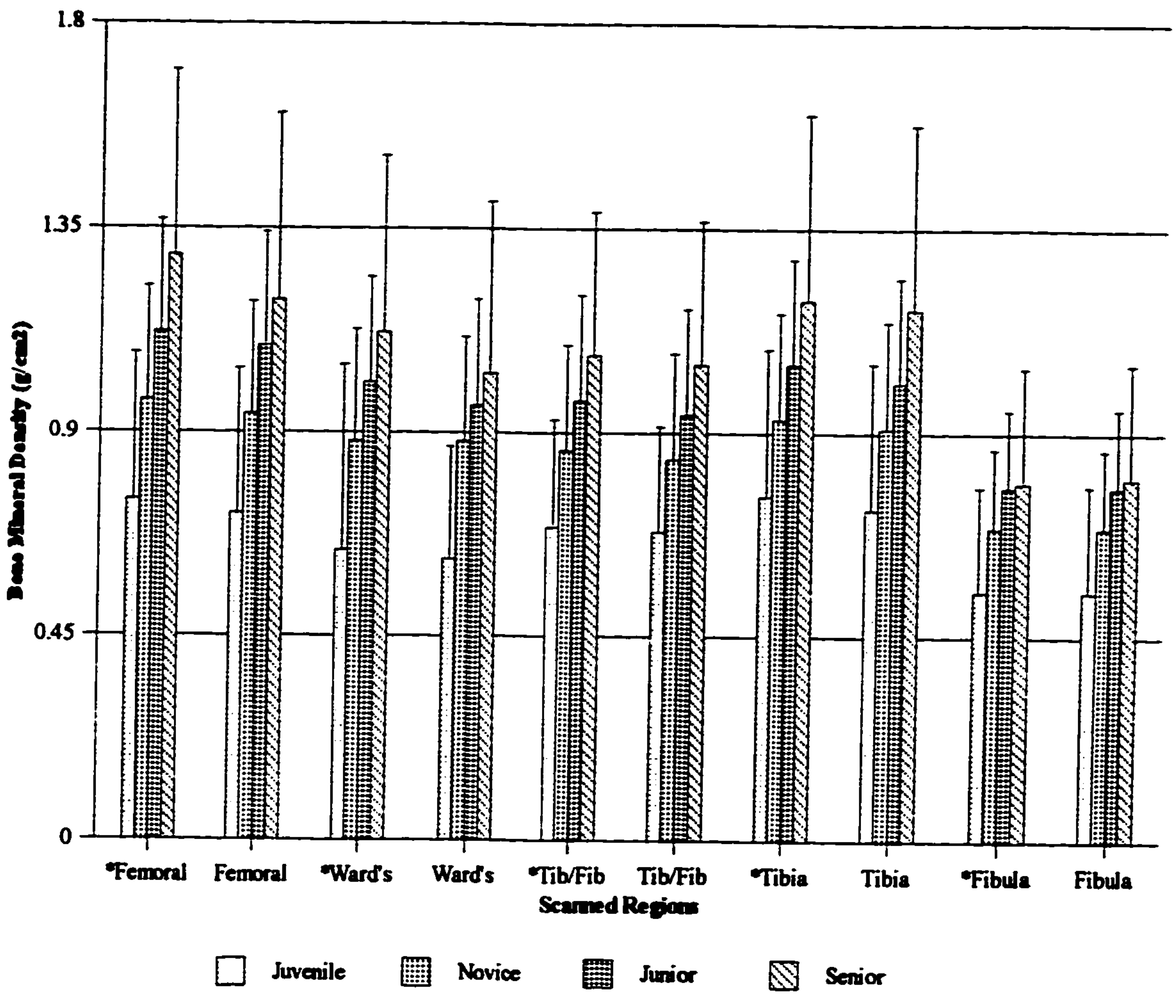


Figure 5a.6 Technical calibre of skater versus bone mineral density (BMD) at selected lower extremity bone sites. Values reported as Mean ± Standard Error.

* Represents dominant limb.

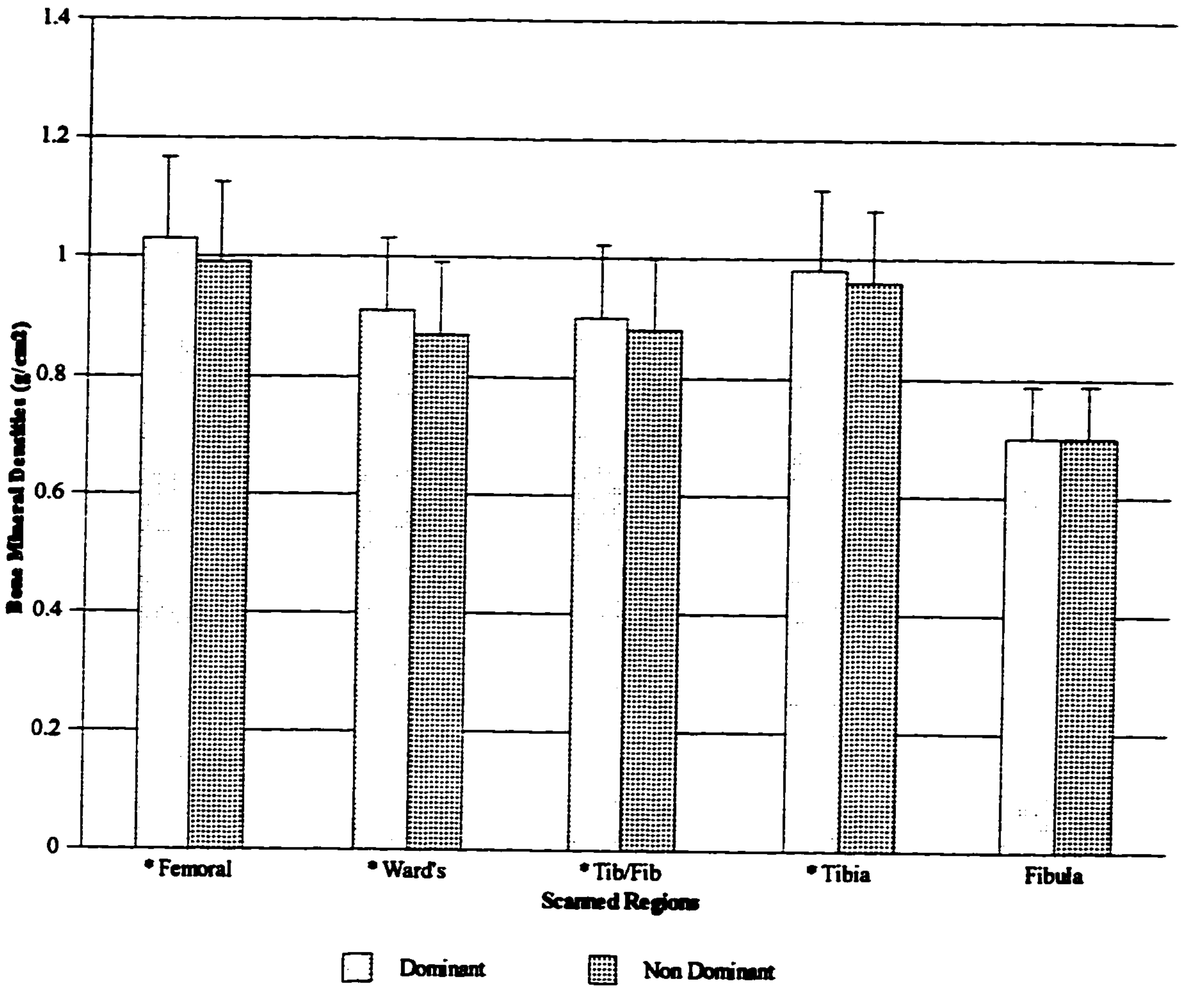


Figure 5a.7 Dominant versus non-dominant bone mineral density (BMD) at selected lower extremity bone sites. Values are reported as Mean ± Standard Error.

* Represents significant difference in BMD between dominant and non-dominant sites.

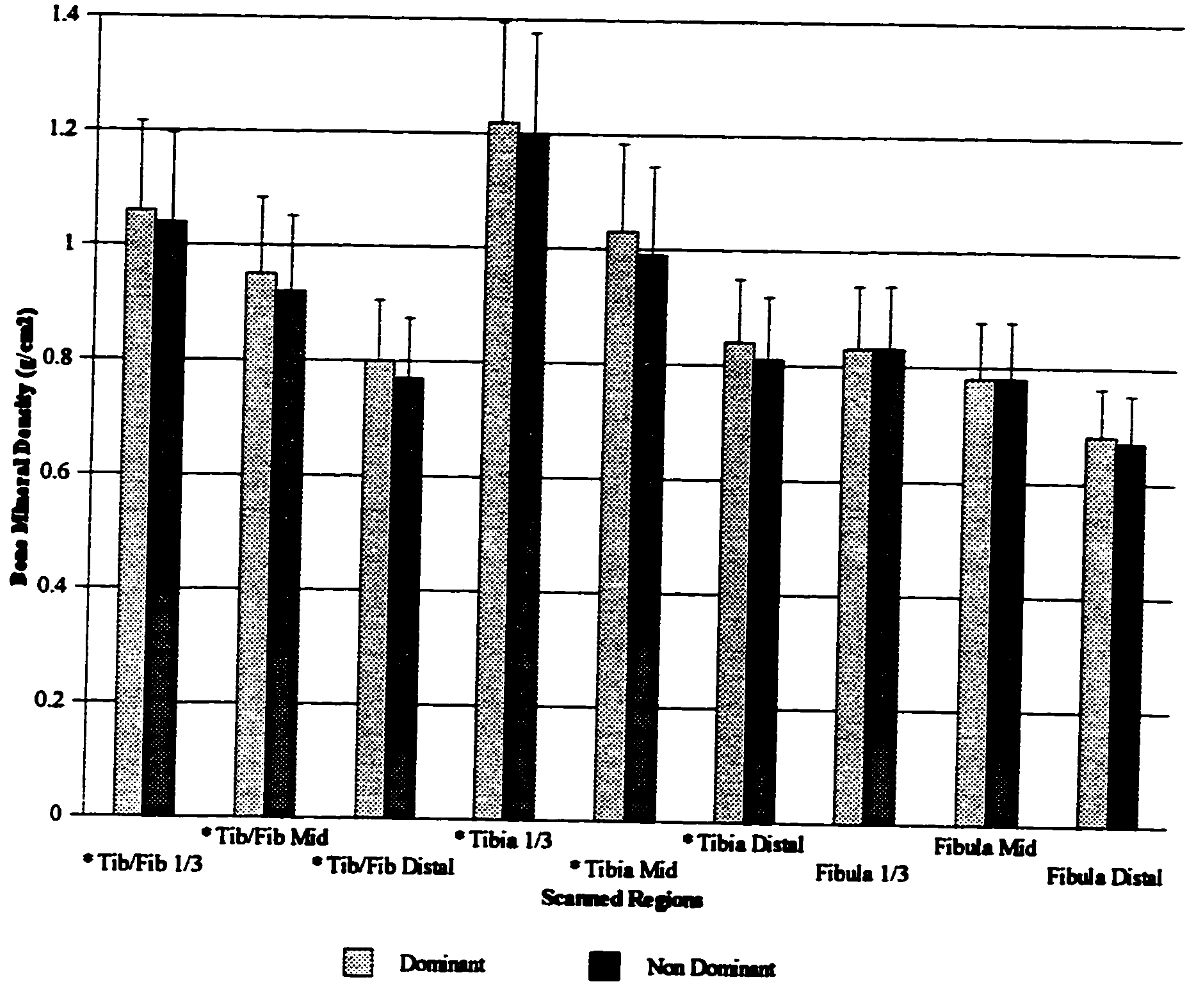


Figure 5a.8 Dominant versus non-dominant bone mineral densities (BMD) in corresponding boot height related bone regions. Values are reported as Mean ± Standard Error.

* Represents significant difference in BMD between dominant and non-dominant lower extremity bone sites.

A COMPARISON OF LOWER EXTREMITY BONE MINERAL DENSITY OF COMPETITIVE FIGURE SKATERS TO NON-TRAINED CONTROLS

Abstract

The purpose of the present study was to examine the role of repetitive impact load-type training on bone mineral measures of the lower extremities. Fifty five competitive figure skaters were matched by gender, race, height (cm), body mass (kg), and maturation with non-trained controls selected from an existing data base representing a larger longitudinal study (Pediatric Bone Mineral Accrual Study, 1996, College of Physical Education, University of Saskatchewan). No significant differences were observed in height, body mass, or maturation level between the two groups. It was hypothesized that the lower extremity bone mineral density (BMD) and bone mineral content (BMC) measures of competitive figure skaters would be significantly different than non-trained controls due to the increased mechanical loading on the skeleton as a result of the impact nature of their training. Dual energy x-ray absorptiometry (DEXA) was used to obtain parameters of bone mineral density and bone mineral content from all subjects at five sites: anterior-posterior L1-L4 lumbar spine, left total hip, left femoral neck, left trochanter, and left Ward's triangle. There was a significant overall gender effect for BMD and BMC at all bone sites examined. Males had higher BMD and BMC values than females in both groups, skaters and controls ($p \leq 0.05$). Statistically higher BMD and BMC measures were found in the skaters versus the controls at all lower extremity sites, at all levels of maturity (maturity Index I-V). BMD and BMC differences between groups ranged from 14.86 - 18.32% and 15.49 - 22.66%, respectively. In conclusion, these data suggest that the observed differences in BMD and BMC may be accounted for by the role of mechanical loading inherent in the training of competitive figure skaters.

Key Words: BMD; BMC; Figure Skaters; Repetitive Impact Loading; Training.

Introduction

Several researchers have documented the relationship between bone mass and specific loading regimes in mature athletes (Fehling *et al.*, 1995; Heinonen *et al.*, 1995; Heinonen *et al.*, 1993; Wolman, 1991; Nilsson & Westlin, 1971). Although genetic factors are probably the strongest predictors of peak bone mass, the effects of mechanical stresses from weight bearing activities and muscle contractions have been reported to have a strong stimulatory effect on bone mass (Rubin *et al.*, 1993). It has also been suggested that bone's responsiveness to mechanical loading, such as weight bearing physical activity, is optimal during childhood and adolescence rather than after maturation (Haapasalo *et al.*, (1996); Slemenda *et al.*, 1994; Forwood & Burr, 1994; Parfitt, 1994). A recent study of the timing of peak bone mass revealed that most of the bone mass at multiple skeletal locations has accumulated by late adolescence (Matkovic *et al.*, 1994). More specifically, Glastre *et al.* (1990) and Matkovic *et al.* (1990) reported that as much as 90% of the total adult bone investment has been deposited by the end of adolescence. Therefore factors that may enhance bone accretion in children and adolescents leading to attainment of an optimal level of peak bone mass have been the focus of recent research.

Although the alterations in size, shape, and density of the skeleton during natural growth and maturation are becoming apparent (Blimkie *et al.*, 1996; Bailey *et al.*, 1996; Southard *et al.*, 1991; McCormick *et al.*, 1991), the specific effect and magnitude of effect of external factors such as mechanical loading, that may influence bone density in children and adolescents, are not as clearly defined. Slemenda and colleagues (1991) documented that children who are more active may emerge from adolescence with a 5-10% greater bone mass and bone density than less active children, depending on the skeletal site. Slemenda *et al.* (1994) also showed that self reported physical activity and growth positively associated with skeletal mineralization in prepubertal boys and girls.

A limited number of sport specific studies have been conducted on circum pubertal athletes contrasting the effects of weight bearing sports such as gymnastics, to non weight bearing activities, such as swimming (McCulloch *et al.*, 1992; Grimston *et al.*, 1993; Cassell *et al.*, 1996). Grimston *et al.* (1993) studied children ages 10-16 years of age who were active in several competitive sports, and found that BMD was greater in children participating in weight bearing sports compared with children participating in non weight bearing sports such as swimming. McCulloch *et al.* (1992) compared weight bearing sites of 68 male and female adolescent soccer players, competitive swimmers, and controls ages 13 to 17 years and concluded that a positive relation exists between weight bearing activity and enhanced BMD at the weight bearing site. More recently, Cassell *et al.* (1996) reconfirmed these results when comparing BMD of 7- to 9-yr-old females gymnasts and swimmers. It may be concluded from these cross sectional studies that, investigations into factors that may affect the attainment of a sufficiently high level of bone density during the growing years under differing loading regimes have recently been the focus of bone research with attempts made to explain the observed differences in BMD by the type, intensity, duration and site of weight bearing of activities of these young athletes.

Thus, the purpose of the present study was to investigate the effect of a history of repetitive impact load-type training on the bone mineral profiles of figure skaters. Bone mineral content and bone mineral density profiles of competitive figure skaters were compared to biologically matched, non-trained controls. It was hypothesized that significant differences in bone mineral measures would exist between the impact-loaded group and the non-trained control group and that a potential dose-response relationship exists between mechanical loading and bone mineral responses of young athletes to repetitive impact load-type training.

Methods and Procedures

Subjects

Fifty five (18 male and 37 female) competitive figure skaters currently training in Edmonton, ranging in chronological age (10 - 26 years), maturation (Maturity Index I-V), and technical calibre (juvenile, novice, junior and senior), were recruited to participate in the study. Figure skaters represented the impact loaded group. Currently, reference BMC and BMD standards for this age range are scarce. Therefore, control data were selected from an existing data pool provided by Dr. D. Bailey, College of Physical Education, University of Saskatchewan. Bone parameter data obtained from the subjects in the impact loaded group were comparatively analysed with non-trained controls, matched for race, gender, body mass (kg), height (cm), and stage of maturation. Non-trained was defined as an individual not actively participating in competitive sport or fitness activities for more than 3 hours per week (Bailey *et al.*, 1994).

An initial meeting was held to inform all subjects and parents of the research design and procedures. At this time, subjects were provided with complete information regarding all aspects of the experimental procedures. In addition, a written explanation of the study was distributed, accompanied by the informed consent document requesting their participation, in accordance with the requirements of the University of Alberta/University Hospital of Alberta Ethics Committee. This document requested the consent of both the parent/guardian and the subject as some of the participants were under 18 years of age (Appendix J).

Experimental Procedures

This project required the impact loaded group (n=55) to complete a bone mineral assessment as outlined in the following text. In addition, data obtained from four individual questionnaires: 1) Activity/Training Inventory, 2) Calcium Frequency Questionnaire, 3) Maturation Index, and 4) Menstrual History Inventory (females only) detailed in Chapter IV were used for comparison and matching of controls (Appendices F-I). All data collection on the impact loaded group was conducted during a two week period, within the competitive season for these athletes.

Bone Densitometry Assessments

Bone mineral content (BMC) and bone mineral density (BMD) were assessed using dual-energy x-ray absorptiometry (DEXA) measured by a Hologic QDR-4500 $_{TM}$ X-ray Bone Densitometer (Garneau Bone Density Laboratory, Edmonton, Alberta) for the impact group and a Hologic QDR-2000 $_{TM}$ X-ray Bone Densitometer (University of Saskatchewan, Saskatoon, Saskatchewan) for the control group at five respective sites: (i) anterior posterior lumbar spine (L1-L4), (ii) left total hip, (iii) left femoral neck, (vi) left Ward's triangle, and (v) left trochanter. These systems both use an x-ray source rather than a radioactive source to image and measure the bone mineral content (BMC) of the designated areas of the body in grams of calcium hydroxy apatite and bone mineral density

(BMD) in grams of calcium hydroxy apatite/cm^2. Dual energy x-ray absorptiometry allows for a rapid, accurate and highly reproducible assessment of bone mineral content with a very low radiation exposure (Glastre et al., 1990). The amount of radiation dose received from this study has been categorized by the University of Alberta Hospitals Radiation Safety Committee as "low level". Although it is impossible to determine with any degree of certainty what will happen to an individual exposed to low levels of radiation, it is the opinion of radiation experts that low levels of radiation can be considered low risk. (University of Alberta - Hospital Radiation Safety Committee). Scanning techniques were performed according to the manufacturers protocols (Appendix K).

Quality Control: Both the Hologic QDR-4500 $_{TM}$ and the Hologic QDR-2000 $_{TM}$ are equipped with quality control (QC) software programs. QC spine phantom scans were performed daily in array mode and QC plots for BMD were reviewed to monitor instrument precision. In the literature, the in vivo precision of DEXA has been found to be approximately 1% for the lumbar spine and 1-2% for the proximal femur (Friedlander *et al.*, 1995). In the Garneau laboratory, the mean coefficients of variation, calculated over a six month period encompassing the two months of testing, have been reported as .35% (BMD) and .52% (BMC) for the lumbar spine. All measurements on each group were performed by the same respective laboratory technician.

Statistical Analysis:

A 2 group (figure skaters/controls) x 2 sex (male/female) analysis of variance was performed to determine significant differences between the impact loaded group and controls, and between sexes. Secondly, a 2 group (figure skaters/controls) x 5 maturity levels (maturity index I-V) analysis of variance was performed to determine if significant differences exist between groups and pubertal stage. Newman Keuls multiple comparison procedures were used if any main or interaction effects were observed. Level of significance for all statistical analyses was set *a priori* at $p \leq 0.05$. Data analyses were performed using Statistica (Stat Soft, Inc., Release 3.1).

Results

As reported previously in Chapter IV, the competitive figure skaters started their competitive careers at the mean age of 7.1 ± 2.2 years and have been training consistently for an average of 7.2 ± 4.2 years. The duration of their on-ice training regimes averaged 10.7 months per year, for 9.2 hours per week. The nature of their on-ice training can be described as primarily repetitive impact loaded, bounding or jump related activities, which mechanically loads the lower extremities and requires that the skater absorbs the shock of landing. In addition, the skaters studied supplemented their on-ice training regimes with 2-4 hours per day of off-ice programs, such as conditioning, dance and choreography.

As illustrated in Table 5b.1, a comparative analysis of the impact loaded group versus the non trained controls characteristics indicated no significant differences between the height, body mass, or maturation index of the figure skaters versus controls. However, the chronological age of controls (13.0 ± 2.4 yrs.) was significantly younger than the figure skaters (15.5 ± 3.9 yrs.). Sex differences appeared in both groups, with males being taller and heavier than the females ($p \leq 0.05$).

In comparison to the control data, BMC and BMD data obtained from a sport specific population revealed significantly higher values at all lower extremity sites examined: lumbar spine, left total hip, left femoral neck, left Ward's, and left trochanter (Table 5b.2). In both groups, figure skaters and controls, BMC and BMD values obtained from males were significantly higher than females (Figure 5b.3 and Figure 5b.4). The relationship between level of maturation (maturity index I-V) and BMD at the five bone sites examined are shown in Table 5b.3. Statistically significant differences in the mean BMD and BMC values were observed both between sexes and between each of the five levels of maturation.

The mean age of menarche was not significantly different between the female figure skaters versus the female controls, however this analysis is only representative of the differences between females reporting menarche. Further investigations revealed that although the reported age of menarche was similar between groups, a number of figure skaters of older chronological ages were still pre-menarcheal and not factored into the analysis. For example, only 64% of the female figure skaters were menarcheal, whereas 74% of the biologically matched, female controls reported menarche. Of further importance, although matched for height, body mass, and maturation index, the figure skaters were also an average of 2.5 years older.

Discussion

Several researchers have suggested that osteoporosis is rooted in childhood and adolescence (McCulloch *et al.*, 1992; Faulkner *et al.*, 1993; Bailey *et al.*, 1996). As a result there has been an extensive amount of research aimed at identifying factors which are proposed to contribute to the stimulation of increased bone mass. Slemenda *et al.*

(1994) stated that more than 90% of peak skeletal mass was present by age 18 and little can be done after this age to increase skeletal mass. Since one of the earliest studies conducted on athletes (Nilsson & Westlin, 1971), it has been speculated that the effect of physical activity on bone was a result of either strain on the skeleton from muscle contraction or from external mechanical forces.

Previous investigations conducted on the loading regimes of figure skaters revealed that the mechanical loading inherent in on-ice jump training produced magnitudes of strain estimated to exceed the MESS threshold (Chapter IIIa). Since the competitive career of a figure skater coincides with the years of skeletal maturation, these strains are being imposed on what could be proposed as an impressionable skeleton.

A number of studies have demonstrated a dramatic increase in BMD accompanying the increase in linear growth during adolescent years in both males and females (Bonjour *et al.*, 1991: McCormick *et al.*, 1991; McCulloch *et al.*, 1993). Results of the present investigation also revealed a parallel relationship between bone mineral measures increasing with advancing age, height, body mass, and maturation. As expected the more developmentally, mature individuals had greater BMD at all sites examined.

In contrast to the literature, which reports a strong correlation between menarche and BMD, the results of the present investigation did not support this finding. Although no significant difference in age of menarche was reported between female skaters and controls, a percentage of female figure skaters had yet to reach menarche, and yet they had superior bone mineral values in comparison to menarcheal controls. A similar finding was documented by Robinson *et al.* (1995) who concluded that the mechanical forces generated from high impact loading and muscular contraction during gymnastics training have powerful osteogenic effects, which appear to compensate for or counteract the increase bone resorption that has been shown to result from oligo- and amenorrhea. Haapasalo *et al.* (1996) reported that there is a significant relationship between subjects who participated in athletics prior to menarche compared to those physically active after. This was not investigated in the present study, however the skaters all started their training well before menarche ($\bar{x} = 7.16 \pm 2.24$ yrs.).

A limitation of the cross sectional nature of this investigation was the inability to determine a specific cause and effect relationship between bone density and loading regime. However, the findings clearly illustrated that the impact loaded group had significantly higher BMD and BMC values at all impact loaded bone sites examined. A limitation to the interpretation of these data was the inability to match subjects on all potentially relevant factors. When figure skaters were matched with controls by weight and height, chronological age of the figure skaters was significantly older than the controls. As illustrated in Chapter IV, the physique of a figure skaters is characterized as being short and lean. Although, the relationship between chronological age and BMD is not as strong as biological age and BMD, this mismatch introduces a confounding factor in the interpretation of the data. However, it is suggested that beyond the limitations imposed by using a comparatively-matched control group, the training of the impact loaded group may have contributed to these differences.

Conclusions

The present study employed a non equivalent control group design to compare the effects of a history of repetitive load-type training on the bone mineral profiles of figure skaters versus a non-trained control group. As hypothesized, the results demonstrated that athletes who engage in a sport such as figure skating, which loads the skeletal system with high magnitude, short duration stimuli had greater BMD and BMC than non-trained controls. These data suggest that the type of mechanical loading regime plays an integral part in influencing BMD and BMC in these young athletes. The results of this study appear to provide further evidence that high magnitudes of mechanical loading regimes may enhance bone mineral measures in this population.

References

Bailey, D., Faulkner, R. & McKay, H. (1996). Growth, physical activity, and bone mineral acquisition. In J. Holloszy (ed.), *Exercise & Sport Science Reviews*, 24:233-266.

Bailey, D. (1994). Invited Paper: Physical activity and the attainment of peak bone mass in children. *The Australian Journal of Science and Medicine in Sport*, 26(½):3-5.

Bailey, R., Olson, J., Pepper, S., Porszazs, J., Barstow, T. & Cooper, D. (1994). The level and tempo of children's physical activities: an observational study. *Medicine and Science in Sports and Exercise*, 27(7): 1033-1041.

Blimkie, C., Chilibeck, P. & Davison, K. (1996). Bone mineralization patterns: Reproductive endocrine, calcium and physical activity influences during the life span. In Bar-Or, D.R. Lamb & P.M. Clarkson (eds.), *Perspectives in Exercise Science and Sports Medicine*, 9: Exercise and the Female: A life span approach, Cooper Publishing Group: 73-145.

Bonjour, J., Theintz, G., Buch, B., Slosman, D. & Rizzoli, R. (1991). Critical years and stages of puberty for spinal and femoral bone mass accumulation during adolescence. *Journal of Clinical Endocrinology and Metabolism*, 73: 555-563.

Cohen, J. (1977). Statistical Power Analysis for the Behavioural Sciences (Revised Edition). Academic Press, New York: 316.

Cassell, C., Benedict, M. & Specker, B. (1996). Bone mineral density in elite 7- to 9-yr-old female gymnasts and swimmers. *Medicine and Science in Sports and Exercise*, 28(10):1243-1246.

Fehling, P., Alekel, L., Clasey, J., Rector, A. & Stillman, R. (1995). A comparison of bone mineral densities among female athletes in impact loading and active loading sports. *Bone*, 17(3): 205-210.

Forwood, M. & Burr, D. (1993). Physical activity and bone mass: exercises in futility? *Bone and Mineral*, 21: 89-112.

Friedlander, A., Genant, H., Sadowsky, S. Byl, N. & Gluer, C. (1995). A two year program of aerobics and weight training enhances bone mineral density of young women. *Journal of Bone and Mineral Research*, 10(4): 574-585.

Glastre, C., Bralillon, P., David, L., Cochat, P., Meunier, P. & Delmas, P. (1990). Measurement of bone mineral content of the lumbar spine by dual energy x-ray absorptiometry in normal children: Correlations with growth parameters. *Journal of Clinical Endocrinology and Metabolism*, 70: 1330-1333.

Grimston, S., Willows, N. & Hanley, D. (1993). Mechanical loading regime and its relationship to bone mineral density in children. *Medicine and Science in Sports and Exercise*, 25: 1203-1210.

Haapasalo, H., Sievanen, H., Kannus, P., Heinonen, A., Oja, P. & Vuori, I. (1996). Dimensions and estimated characteristics of the humerus after long term tennis loading. *Journal of Bone and Mineral Research*, 11(6): 864-872.

Heinonen, A., Oja, P., Kannus, P., Sievanen, H., Manttari, A. & Vuori, I. (1993). Bone mineral density of female athletes in different sports. *Bone & Mineral*, 2: 1-14.

Heinonen, A., Oha, P., Kannus, P., Sievanen, H., Haapasalo, H., Manttari, A. & Vuori, I. (1995). Bone mineral density in female athletes representing sports with different loading characteristics of the skeleton. *Bone*, 17(3): 197-203.

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

Matkovic, V., Fontana, D., Tominac, C., Goel, P. & Chestnut III, C. (1990). Factors that influence peak bone mass formation: a study calcium balance and an inheritance of bone mass in adolescent females. *American Journal of Clinical Nutrition*, 52: 878-888.

McCormick, D., Ponder, S., Fawcett, H. & Palmer, J. (1991). Spinal bone mineral density in 335 normal and obese children and adolescents: evidence for ethnic and sex differences. *Journal of Bone Mineral Research*, 6: 507-513.

McCulloch, R., Bailey, D. Whalen, R., Houston, C. Faulkner, R & Craven B. (1992). Bone density and bone mineral content of adolescent soccer athletes and competitive swimmers. *Pediatric Exercise Science*, 4: 319-330.

Nilsson, B. & Westlin, N. (1971). Bone density in athletes. *Clinical Orthopaedic and Related Research*, 77: 179-182.

Parfitt, A. (1994). The two faces of growth: benefits and risks to bone integrity. *Osteoporosis International*, 4:382-298.

Robinson, T., Snow-Harter, C., Taaffe, D., Gilles, D., Shaw, J. & Marcus, R. (1995). Gymnasts exhibit higher bone mass than runners despite similar prevalence of amenorrhea and oligomenorrhea. *Journal of Bone and Mineral Research*, 10(1): 26-35.

Rubin, K., Schirduan, V., Gendreau, P., Sarfarazi, M., Mendola, R. & Dalsky, G. (1993). Predictors of axial and peripheral bone mineral density in healthy children and adolescents, with special attention to the role of puberty. *Journal of Pediatrics*, 123: 863-870.

Slemenda, C., Miller, J., Hui, S., Reister, T. & Johnston, C. (1991). Role of physical activity in the development of skeletal mass in children. *Journal of Bone and Mineral Research*, 6(11): 1227-1233.

Slemenda, C., Reister, T., Hui, S., Miller, J., Christian, J. & Johnston, C. (1994). Influences of skeletal mineralization in children and adolescents: evidence for varying effects of sexual maturation and physical activity. *Journal of Pediatrics*, 1125: 201-207.

Southard, R., Morris, J., Mahan, J., Hayes, J., Torch, M., Sommer, A. & Zipf, W. (1991). Bone mass in healthy children: Measurement with quantitative DXA. *Radiology*, 179: 735-738.

Wolman, R., Faulmann, L., Clark, P., Hesp., R. & Harries, M. (1991). Different training patterns and bone mineral density of the femoral shaft in elite, female athletes. *Annals of the Rheumatic Diseases*, 50: 487- 489.

Table 5b.1 Comparative Subject Characteristics. Values are reported as Means ± Standard Deviations.

	Figure Skaters			Controls		
Group	Group	Male	Female	Group	Male	Female
Gender Population	n = 55	n = 18	n = 37	n = 55	n = 18	n = 37
Height (cm) *	159.2 ± 13.5	172.1 ± 12.0	154.3 ± 10.5	159.5 ± 13.3	172.1 ± 10.5	154.6 ± 10.9
Body Mass (kg) *	51.1 ± 13.4	62.3 ± 13.4	46.8 ± 10.8	51.0 ± 14.1	63.5 ± 15.1	46.2 ± 10.5
Chronological Age at Test (yrs)*†	15.5 ± 3.9	19.1 ± 4.4	14.6 ± 2.7	13.0 ± 2.4	14.7 ± 2.2	12.4 ± 2.2
Age at Menarche (females)	n/a	n/a	12.8 ± 1.0	n/a	n/a	12.3 ± .9

* Statistically significant difference between genders within group ($p \leq 0.05$).
† Statistically significant difference between groups: figure skaters versus controls ($p \leq 0.05$)

Table 5b.2 Lower extremity BMC and BMD measures of competitive figure skaters versus matched non trained controls. Values are reported as Means ± Standard Deviations.

	Figure Skaters (n=55)		Controls (n=55)		Percent Difference (%)	
	BMC	BMD	BMC	BMD	BMC	BMD
L1-L4 Lumbar Spine *	51.37 ± 18.82	0.944 ± 0.191	41.95 ± 16.54	0.800 ± 0.160	19.3	15.3
Left Total Hip *	34.43 ± 11.58	1.025 ± 0.183	26.63 ± 10.91	0.837 ± 0.177	22.66	18.32
Left Femoral Neck *	4.786 ± 1.33	0.944 ± 0.177	3.871 ± 1.131	0.789 ± 0.159	29.12	16.48
Left Ward's Triangle *	1.092 ± .2558	0.917 ± 0.198	0.922 ± 0.223	0.781 ± 0.169	15.49	14.86
Left Trochanter *	8.301 ± 3.221	0.827 ± 0.154	6.781 ± 3.172	0.696 ± 0.155	18.32	15.84

* Statistically significant difference between groups: figure skaters versus controls ($p \leq 0.05$)

Table 5b.3 Lower extremity BMD measures of competitive figure skaters versus controls at five respective stages of maturation. Values are reported as Means ± Standard Deviations.

	Maturity Index (Tanner's Stages)				
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**
L1-L4 Lumbar Spine * †					
Figure Skaters	0.603 ± 0.028	0.715 ± 0.074	0.860 ± 0.186	0.965 ± 0.119	1.091 ± 0.100
Controls	--	0.679 ± 0.047	0.715 ± 0.126	0.844 ± 0.091	0.947 ± 0.143
Left Total Hip * †					
Figure Skaters	0.685 ± 0.029	0.798 ± 0.121	0.964 ± 0.173	1.071 ± 0.116	1.145 ± 0.103
Controls	--	0.735 ± 0.079	0.751 ± 0.151	0.882 ± 0.149	0.963 ± 0.165
Left Femoral Neck * †					
Figure Skaters	0.636 ± 0.044	0.768 ± 0.106	0.873 ± 0.160	0.997 ± 0.120	1.043 ± 0.143
Controls	--	0.723 ± 0.049	0.720 ± 0.143	0.828 ± 0.138	0.885 ± 0.160
Left Wards Triangle * †					
Figure Skaters	0.627 ± 0.066	0.734 ± 0.135	0.824 ± 0.200	0.981 ± 0.189	1.017 ± 0.130
Controls	--	0.732 ± 0.068	0.719 ± 0.188	0.838 ± 0.170	0.843 ± 0.135
Left Trochanter * †					
Figure Skaters	0.560 ± 0.040	0.626 ± 0.098	0.788 ± 0.098	0.882 ± 0.094	0.912 ± 0.100
Controls	--	0.586 ± 0.074	0.629 ± 0.145	0.735 ± 0.144	0.801 ± 0.136

* Statistically significant difference between groups; figure skaters versus controls ($p \leq 0.05$).
† Statistically significant difference between stages of maturity ($p \leq 0.05$).

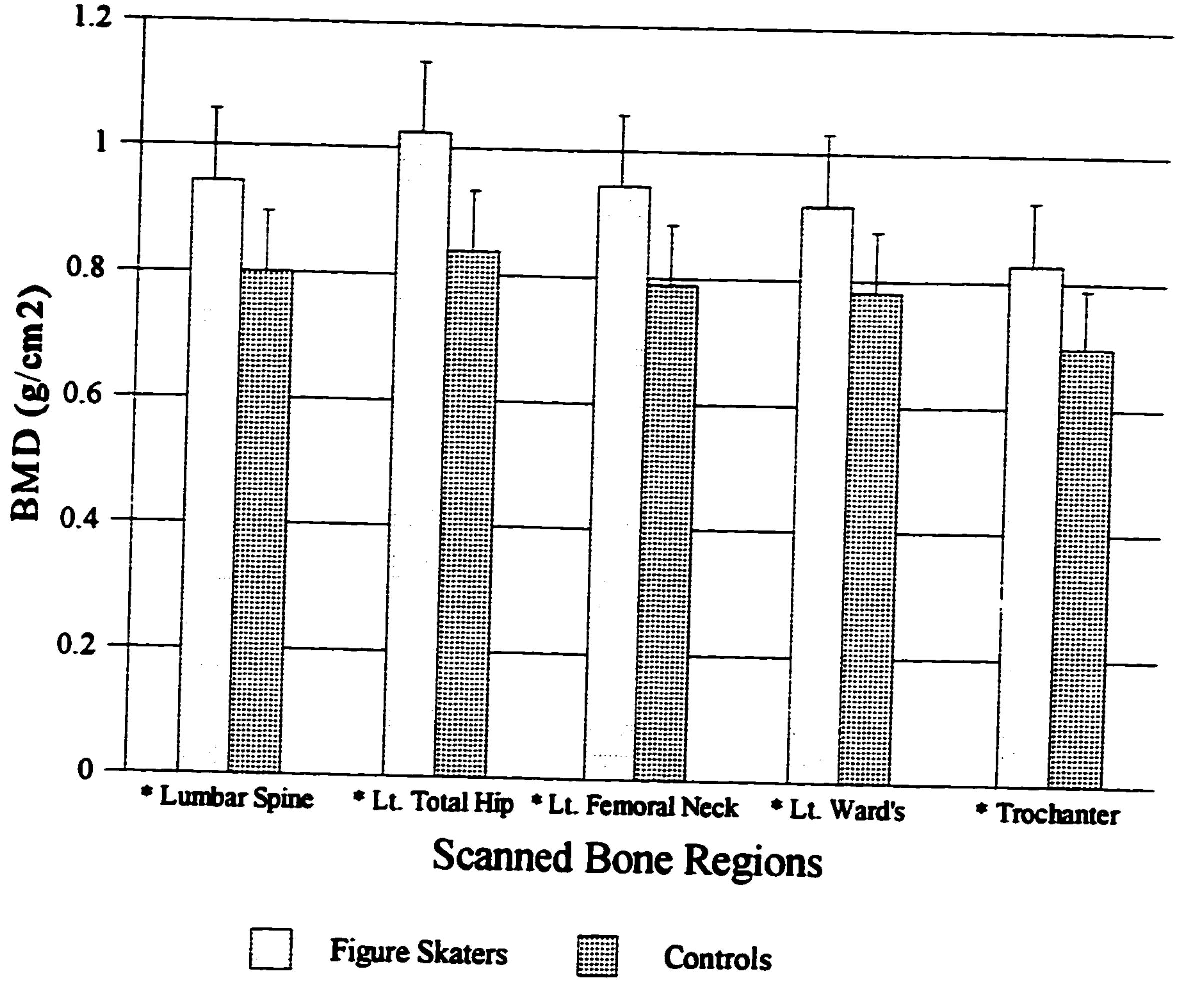


Figure 5b.1 Lower extremity bone mineral density measures (BMD) of competitive figure skaters in comparison to non trained controls. Values are reported as Mean ± Standard Error.

* Represents significant differences between groups ($p \leq 0.05$).

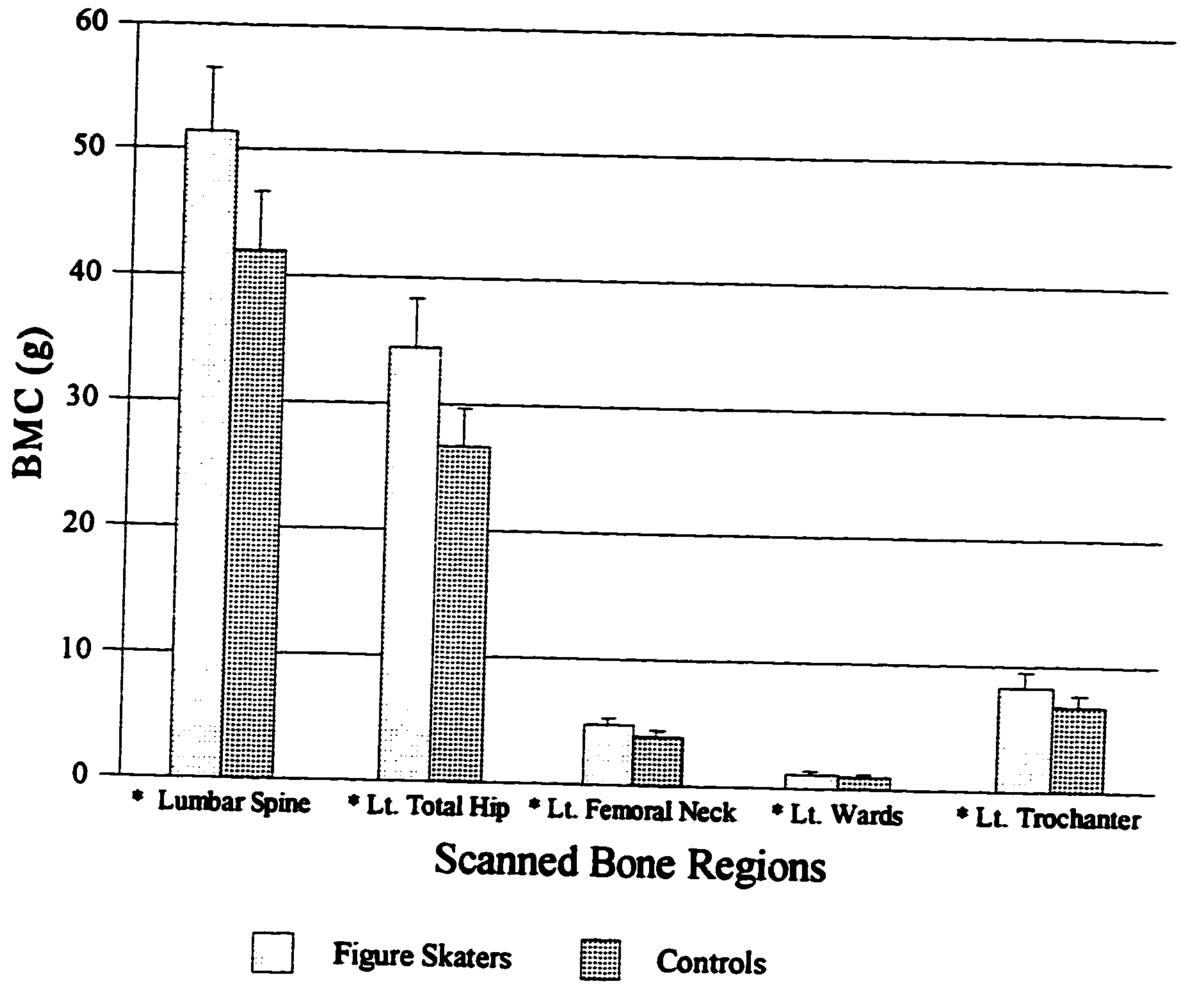


Figure 5b.2 Lower extremity bone mineral content measures (BMC) of competitive figure skaters in comparison to non trained controls. Values are reported as Mean ± Standard Error.

* Represents significant differences between groups ($p \leq 0.05$).

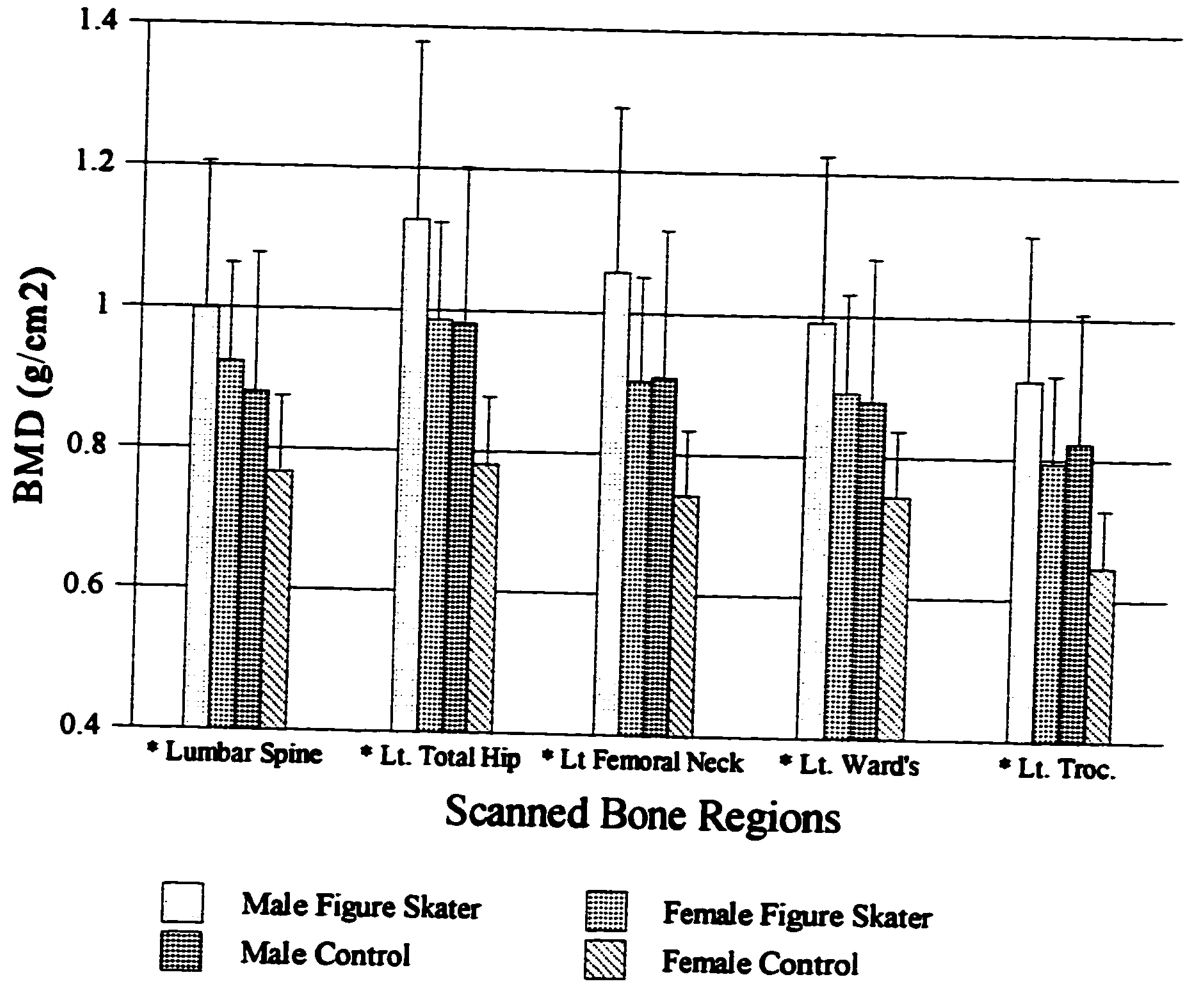


Figure 5b.3 Sex differences in BMD among competitive figure skaters versus non trained controls. Values are reported as Mean ± Standard Error.

* Represents significant differences between both group and sex ($p \leq 0.05$).

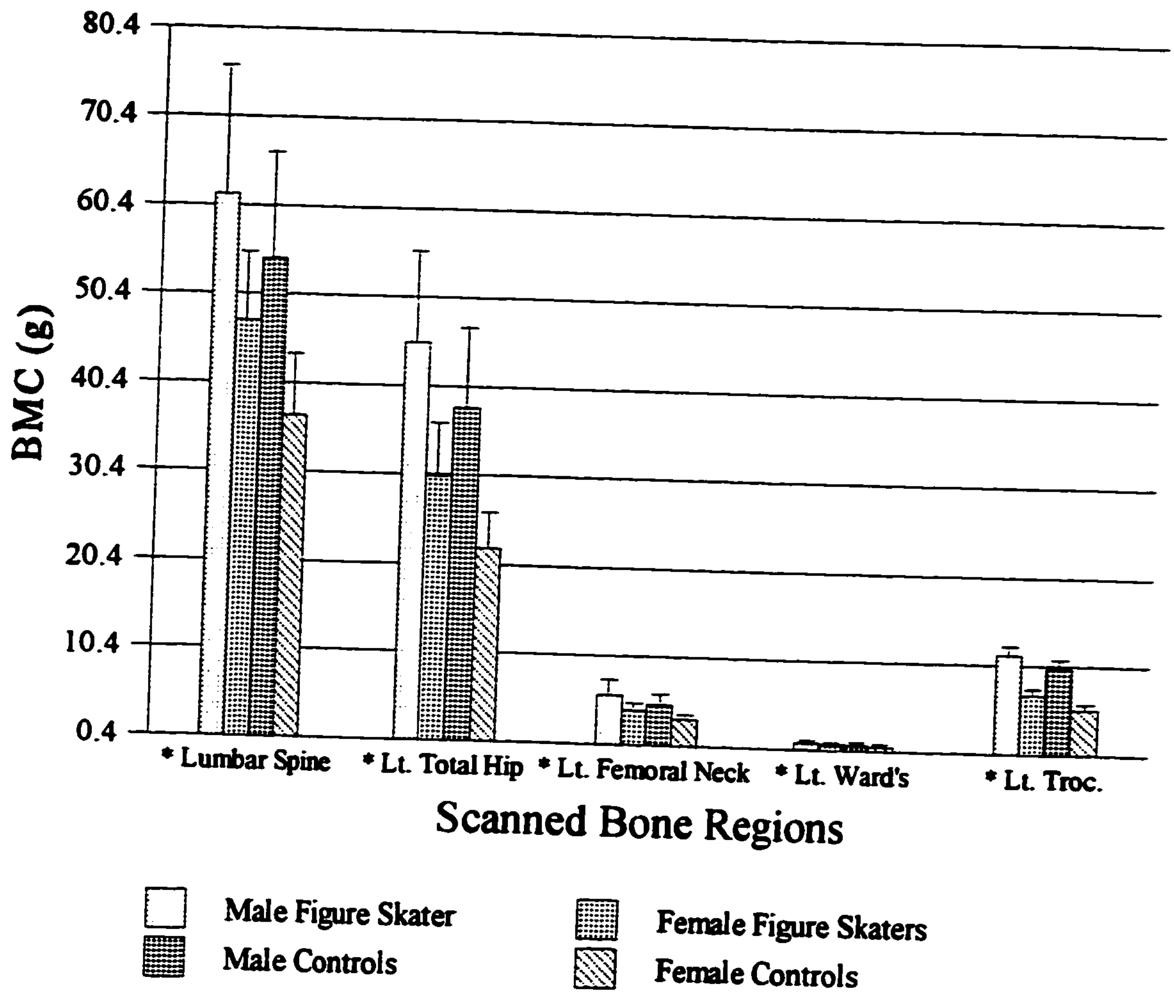


Figure 5b.4 Sex differences in BMC among competitive figure skaters versus non trained controls. Values are reported as Mean ± Standard Error.

* Represents significant differences between groups and sex ($p \leq 0.05$).

CHAPTER SIX

Biochemical Markers of Bone Turnover

Project VI

BIOCHEMICAL MARKERS OF BONE TURNOVER IN "IMPACT TRAINED" COMPETITIVE FIGURE SKATERS

BIOCHEMICAL MARKERS OF BONE TURNOVER IN "IMPACT TRAINED" COMPETITIVE FIGURE SKATERS

Abstract

In this study, it was hypothesized that impact load-type training induces an adaptive response in the developing skeleton which may be observed by measuring biochemical markers of bone metabolism. Fifty five competitive figure skaters ranging in age (10-26 years), maturation (maturity index 1-5), and technical calibre (juvenile, novice, junior and senior) gave informed consent to participate in the study. Biochemical markers used to indicate bone turnover were: parathyroid hormone (N-Tack-PTH), osteocalcin (Os), 25 hydroxy vitamin D (25-OH-D), carboxy terminal propeptide of type I collagen (PICP), carboxy terminal telopeptide of type I collagen (ICTP) and serum calcium (Ca). Maturation, defined by a self reported maturation index, paralleled chronological age, technical calibre, and years of competitive impact load type training. No significant effect of sex was observed for any of the biochemical indices among groups of technical calibre or maturation. Three of the six markers examined: osteocalcin, PICP, and ICTP showed significant differences between calibre of skaters and stage of maturation. Biochemical profiles of the senior skaters (maturity index V) were significantly depressed in comparison to the other three calibres. Two markers of bone turnover (osteocalcin and PICP) were greatest in the juvenile skaters (maturity index I) and lower in the technically advanced and more mature skaters. ICTP was highest in the juvenile, novice, and junior calibres, but was significantly lower in the senior skaters. From this investigation it was impossible to determine whether the biochemical profiles of these athletes were reflective of age, maturation, and/or training. Data was presented in comparison to published norms for each respective marker. These analyses were also further confounded as the differences between markers may also reflect differences in the bone specificity of the analytes or differing mechanisms of production and clearance.

Key Words: Biochemical Indices; Bone Formation; Bone Resorption; Figure Skaters; Impact Loading.

Introduction

Of the many factors influencing skeletal development and integrity, physical activity has been identified as probably the most important (Bailey *et al.*, 1994). Numerous studies have reported that bone density was significantly higher in athletes than age-matched controls (Nilsson & Westlin, 1971; Wolman *et al.*, 1991; Heinonen *et al.*, 1993; Slemenda & Johnston, 1993; Nichols *et al.*, 1994; Fehling *et al.*, 1995; Robinson *et al.*, 1995). Recent inquires have suggested that in addition to the structural responses of the skeleton to biomechanical stress, such as increased bone mineral density, mechanical or impact load-type exercise may influence skeletal metabolism via changes in biochemical profiles (Blumsohn *et al.*, 1994; Nichols et al.1994). Experimental investigations have revealed that bone cells are sensitive and stimulated by mechanical influences (Rubin & Lanyon, 1984; Skerry *et al.*, 1989; Klein-Nulend *et al.*, 1995).

The development of biochemical assays used to measure the products of bone cells that mediate the processes of bone formation and resorption has provided a means to assess bone turnover and more specifically, the overall skeletal response to levels of physical activity. Unlike the method of dual energy X-ray absorptiometry (DEXA) which measures bone mineral content (BMC) and bone mineral density (BMD) of a specific bone site, serum levels are indicative of changes within the entire skeleton. Furthermore, because of the low normal bone turnover, it takes months, if not years before changes in bone mass can be detected by DEXA. Biochemical markers of bone metabolism have the advantage of reflecting alterations in bone turnover within weeks which allows for rapid evaluation and more precise monitoring (Akesson, 1995).

Bone metabolism is characterized by two opposite activities: the formation of new bone by osteoblasts and the degradation of old bone by osteoclasts (Delmas, 1993). The rate of formation or degradation of the bone matrix can be assessed by measuring bone matrix components that have been released into circulation during formation and resorption. It has been proposed from animal studies that these biochemical markers may provide a sensitive, non invasive method of monitoring skeletal turnover during athletic activity (Price *et al.*,1995).

To date, there are limited accounts of exercise regime studies on human bone metabolism. Nichols *et al.* (1994) investigated the effect of 27 weeks of gymnastics training on both bone mineral density and selected biochemical indices. Significant differences were observed in bone mineral density of the lumbar spine and femoral neck. Serum osteocalcin levels in the gymnasts were significantly higher than controls, however no differences were observed after 27 weeks of training. Other studies combining bone mass measurements and biochemical assessments of bone turnover have revealed controversial results. Two independent studies claimed that in untreated post menopausal women followed for 2-4 years, serum osteocalcin was the best single biochemical marker reflecting the spontaneous rate of bone loss assessed by repeated measurements of the bone mineral content of the radius and the lumbar spine; the higher bone turnover rate, the higher the rate of bone loss (Delmas, 1993). More recently, Lotz *et al.* (1995) reported no significant relationships between BMD and selected markers of bone formation and resorption.

In contrast to loading, it has been demonstrated that prolonged periods of skeletal unloading leads to a negative biochemical response resulting in conditions such as disuse osteoporosis. Lueken *et al.* (1993) demonstrated an increase in bone resorption during bed rest, with values reaching peaks after 4 days of bed rest and remaining elevated for 6 weeks after ambulation. Findings such as these have aroused researchers' interest and inquiry into the biochemical responses of bone to mechanical loading and more specifically, physical activity.

Markers of Bone Turnover

Parathyroid Hormone (N-Tack PTH): PTH is one of three hormones regulating calcium homeostasis, the others being calcitonin and the active form of 25-hydroxy vitamin D. The normal release of PTH from the thyroid gland is a classic example of a negative feedback control mechanism. As the blood ionic calcium level falls, the parathyroids synthesize and release PTH; as the blood ionic calcium levels rise, the synthesis and release of PTH from the glands is inhibited. The catabolic effect of PTH on bone appears to be the net result of stimulation of osteoclast bone resorbing activities and inhibition of osteoblast bone forming activities (Peck, 1986). PTH promotes the mobilization of calcium by stimulating osteoclast activity and calcium resorption. Full physiological activity of PTH resides within the N-terminal 1-4 amino acid sequence of the molecule, or commonly referred to as N-Tack PTH (McCann *et al.*, 1986).

Osteocalcin (Os): Since its discovery in 1975, evidence suggests that osteocalcin is a bone specific protein, and is mainly if not entirely reflective of bone formation (Kruse & Kracht, 1986). Osteocalcin is produced by bone forming cells, the osteoblasts. The majority is stored in the extracellular matrix of bone, however a fraction is released into circulation where it can be measured. Synthesis and release of osteocalcin into circulation is stimulated by 25 hydroxy vitamin D (Delmas *et al.*, 1990). Clinical investigations conducted in children have led to the conclusion that circulating osteocalcin is a marker of bone growth in normal and abnormal conditions reaching high levels during childhood, decreasing levels during adolescence and being the lowest after the age of 18 with no apparent differences between genders (Delmas *et al.*, 1990; Kruse & Kracht, 1986). In adults, osteocalcin is inversely related to BMD (Akesson, 1995).

25 Hydroxy Vitamin D: It has been well established that vitamin D nutritional status is a function of circulating 25-hydroxy calciferol. These compounds exist in two forms: cholecalciferol (vitamin D_3), which is synthesized in the epidermis, and ergocalciferol (vitamin D_2), derived solely from plant sources. Thus, the overall vitamin D status of the individual depends on endogenous (sun exposure) and exogenous (dietary intake) sources and measurement of both forms is important (Hollis *et al.*, 1993). In addition to parallelling fluctuations in PTH, 25-hydroxy vitamin D stimulates osteoblast activity to increase production of osteocalcin, thus is assessed as a marker of bone formation activity.

Carboxy Terminal Propeptide of Type I Collagen (PICP): Type I collagen constitutes more than 90% of the organic bone matrix (Charles *et al.*, 1994). PICP is released into circulation in the blood only during the synthesis of collagen and is therefore representative of bone formation. Studies in humans have shown that serum levels of PICP reflect the rate of bone formation during skeletal growth and in metabolic bone diseases (Blumsohn *et al.*, 1994; Eriksen *et al.*, 1993; Trivedi *et al.*, 1991).

Carboxy Terminal Telopeptide of Type I Collagen(ICPT): Bone resorption is charactertized by the degradation of the collagenous matrix. ICPT is excreted through collagen degradation and therefore classified as an index of bone resorption. Markers of resorption have been shown to peak in the first year of life and in mid puberty, then decrease toward adult life. Charles *et al.* (1994) concluded that PICP and ICPT reflect whole skeletal bone formation and resorption rates respectively in a variety of metabolic bone diseases and in normal bone development.

Calcium: Serum calcium level is closely regulated by PTH and 25-hydroxyvitamin D by controlling intestinal absorption and kidney excretion, whereas the skeleton is considered mainly to be a reserve (Akesson, 1995). Calcium is known to be a threshold nutrient; below a critical level (the threshold) calcium availability limits bone accumulation (Bell, 1983). In contrast, Johnston *et al.* (1992) indicated that calcium supplementation of 1200 mg/day in adolescent boys and girls leads to increased bone acquisition. However, additional increases in calcium intake in excess of recommended nutrient requirement (RNI) had little or no effect on bone mass. The mechanism by which inadequate calcium intake may promote bone loss was thought to be via a PTH-dependent increase in bone remodeling.

These biochemical markers have been proposed to reflect minor changes of bone turnover. Therefore the present study compared six markers to determine if they reflect differences between levels of maturation, and repetitive impact load-type training. It was hypothesized that bone turnover as reflected by fluctuations in biochemical indices parallel maturation and may be stimulated by mechancial loading or physical activity, which would be inherent in the training of competitive figure skaters.

Methods and Procedures

Subjects

Fifty five competitive figure skaters of both genders, ranging in age (10-26 years) and technical calibre (juvenile, novice, junior and senior) volunteered to participate in the study. Subjects were healthy and not taking medications known to influence bone metabolism. Stage of maturation was determined using a self reported maturity index (Bailey *et al.*, 1994). Descriptive characteristics of subjects are outlined in Table 6.1. Written informed consents were obtained from both subjects and parents of subjects under 18 years of age. Ethical approval for this study was granted by the Human Ethics Committee in the Faculty of Physical Education, University of Alberta.

Biochemical Procedures

Morning venipuncture blood samples (10 ml) were collected at rest by a qualified phlebotomist. Blood was centrifuged at 3000 x gravity after clotting for 30 minutes at room temperature to separate serum. Serum samples were divided into seven alloquots and frozen at -80 degrees Celsius until assayed. Six assays were completed to investigate the potential of biochemical markers in detecting the degree of bone resorption and formation. Parathyroid hormone (PTH), osteocalcin, 25-hydroxy vitamin D, carboxy terminal telopeptide of type I collagen (ICTP), and carboxy terminal propeptide of type I collagen (PCTP) were quantified using direct commercial radio-immune assay methods (INCSTAR Corporation, Stillwater, MN, U.S.A.). Serum calcium was also quantitatively determined by a commercially prepared method (Biopacific Diagnostic Inc., Vancouver, British Columbia). All samples were assayed in duplicate and means reported. The intra-assay coefficient of variation for each analyte are reported in Table 6.2

Statistical Analysis

Two independent analyses of variance were performed to detect differences between the 1) maturation and biochemical markers of bone turnover, and 2) technical calibre (juvenile, novice junior, senior) of skater and biochemical markers of bone turnover. Newman Keuls post hoc evaluations were performed where required. Level of significance was set *a prior* at $p \leq 0.05$. Group means of each respective biochemical marker were also graphically compared to chronological age matched norms obtained from the most recent literature.

Results

Distribution of sex, mean age, maturation indices, and technical calibre are illustrated in Table 6.1. Since there were no significant sex differences observed between the means of any of the biochemical indices measured, sexes were grouped for further analyses. Furthermore, small group size became a limitation to segmenting data for further analyses. Maturation as defined by a self reported maturation index (Bailey *et al.*, 1994) paralleled chronological age, technical calibre, and years of competitive impact load-type training. Significant differences were not observed in PTH (Figure 6.1), 25-OH-D (Figure 6.2), or calcium (Figure 6.3). Bone turnover, as reflected by serum levels of osteocalcin (Figure 6.4) and PICP (Figure 6.5), was greatest in the juvenile skaters (maturity index I) and decreased significantly in the technically advanced and more mature skaters (maturity index V). ICTP (Figure 6.6), also varied significantly with pubertal stage and was highest in the novice skaters (maturity index II). Significantly lower levels of osteocalcin, PICP, and ICTP were observed only in the senior calibre of skaters when compared to the other calibres, representing stage V of maturation. These findings show that marked differences in biochemical profiles were evident in the more mature skeletons of the advanced skaters.

Discussion

Competitive training in the sport of figure skating is characterized by repetitive impact load-type activity experienced specifically during the training of on-ice jumping. All skaters participating in the study had trained competitively for a minimum of three years, starting between the ages of 5.8 and 7.7 years, which represents a pre pubescent population (maturity index I). In a recent review article, Chilibeck *et al.* (1995) summarized the earlier work of Lanyon & Rubin (1984) and concluded that physical activities designed to increase bone mass and strength should involve loads of high magnitude and rate, be dynamic in nature and involve varied and diverse patterns of stress. This pattern of activity is innate to the competitive figure skater as suggested by their training that has the potential to maximize bone mass. Furthermore, the age at which bone is most responsive to external influences has been suggested to be during maturation (Bailey *et al.*, 1994). As indicated by the young starting age of competitive training, skaters train to reach their peak performances during their young teens which corresponds with peak pubertal years.

During childhood and adolescence, biochemical markers of bone turnover parallel linear bone growth that increase in association with growth spurts and decline with the slowing of linear bone growth and epiphyseal maturation (Blumsohn *et al.*, 1994). In diseased populations, markers of bone turnover have been used to assess children with growth disorders and to monitor the response to growth hormone therapy. However, normative data on markers of bone turnover during puberty are scant with respect to a healthy population.

Athletes are generally stronger, tend to have more lean tissue than non athletes primarily due to training, and may be expected to have higher bone mineral densities than sedentary populations. Competitive figure skaters train an average of 20 hours per week, engaging in activities that increase stress on their bones. This sport also demands a very low percent body fat in order to maximize strength to body weight ratio and project an aesthetic image. Consequently, some figure skaters may overtrain or engage in poor dietary practices which may result in a condition which may compromise bone health. The findings of this study did not support a compromised skeletal structure but rather found relatively normal or elevated levels of bone formation in all respective calibres of skaters.

The highest levels of two of the indices of bone turnover (osteocalcin and PICP) were found in juvenile skaters (Figure 6.7). High serum markers during this group were not unexpected given the higher rates of bone turnover in human subjects which have not yet reached skeletal maturation. However, when data were analysed by maturity indices (I-V), these peaks were found in stages II and III of maturation. As illustrated in Figure 6.8, with the exception of calcium, all biocehmcial markers were highest in stage II and III of maturation as determined by self assessments. The results of this investigation parallel the previous work of Blumsohn *et al.* (1994) that reported levels of all formation markers were maximal in Tanner stages II and III and decreased significantly toward the adult range in Tanner stages IV and V. By stage Vof maturation, closure of growth plates is almost complete, representing a mature skeleton. These changes are consistent with previous findings of Price *et al.* (1995) which demonstrated decreases as skeletal maturity is approached. In the present study, all markers were significantly lower after menarche which is in agreement with Blumsohn *et al.* (1994). It has been concluded that biochemical markers of bone turnover respond in parallel during puberty, but not all markers respond to the same extent. These differences may reflect differences in the bone specificity of the different markers, or the differing mechanisms of production and clearance. In the evaluation of biochemical markers, it is necessary to consider that the release and clearance may be affected by different systemic factors influencing the sensitivity and specificity of the markers.

It is presently unclear what contribution impact training made to the observed serum levels of bone markers. Figure 6.7 and figure 6.8 illustrate the similarity of grouping subjects by maturation vs. technical calibre. It may be a possibility that the mechanical forces imposed on this group influenced the rate of bone turnover, however this cannot be differentiated from the influence of growth and maturation.

Conclusions

An interpretation of these findings suggested that during the early stages of maturation, peak values of bone turnover are observed. Biochemical markers of bone turnover were lowest as the skeleton approached maturity, but not all markers changed to the same extent.

In conclusion, this study has not conclusively shown that measurements of biochemical indices of bone turnover have the potential for monitoring impact load-type training regimes. A clear understanding of the contribution of puberty to this process is required to be able to account for the confounding effects such as maturation. A major limitation of the present study was the lack of age matched sedentary controls. Without a control group, it is impossible to determine the specific effects of maturation versus the combined effect of maturation and training.

References

Akesson, K. (1995). Biochemical markers of bone turnover: a review. *Acta Orthop Scand.*, 66(4) 376-386.

Bailey, D., (1994). Invited Paper: Physical activity and the attainment of peak bone mass in children. *The Australian Journal of Science and Medicine in Sport*, 26(½):3-5.

Bell, N. (1983). Normal physiology of calcium homeostasis. *American Association for Clinical Chemistry*, 2(3), September: 1-2.

Blumsohn, A., Hannon, R., Wrate, R., Barton, J., Al-Dehaimi, A., Colwell, A. & Eastell, R. (1994). Biochemical markers of bone turnover in girls during puberty. *Clinical Endocrinology*, 40: 633-670.

Charles, P., Mosekilde, L., Risteli, L., Risteli, J. & Eriksen, E. (1994). Assessment of bone remodeling using biochemical indicators of type I collagen synthesis and degradation: relation to calcium kinetics. *Bone and Mineral*, 24: 81-94.

Delmas, P. (1993) Biochemical markers of bone turnover. *Journal of Bone and Mineral Research*, 8(2): 549-S555.

Delmas, P., Christiansen, C., Mann, K. & Price, P. (1990). Bone gla protein (osteocalcin) assay standardization report. *Journal of Bone and Mineral Research*, 5(1): 5-11.

Fehling, P., Alekel, L., Clasey, J., Rector, A. & Stillman, R. (1995). A comparison of bone mineral densities among female athletes in impact loading and active loading sports. *Bone*, 17(3): 205-210.

Heinonen, A., Oja, P., Kannus, P., Sievanen, H., Manttarri, A. & Vuori, I. (1993). Bone mineral density of female athletes in different sports. *Bone and Mineral*, 23: 1-13.

Hollis, B., Kamerud, J., Selvaag, S., Lorenz, J. & Napoli, J. (1993). Determination of vitamin D status by radioimmunoassay with an ^{125} I-labeled tracer. *Clinical Chemistry*, 39 (3): 529-533.

Johnston, C., Miller, A., Slemenda, C., Reister, T., Huit, S., Christian, J. & Peacock, M. (1992). Calcium supplementation and increases in bone mineral density in children. *New England Jouranl of Medicine*, 327: 82-87.

Klein-Nulend, J., Van Der Plas, A., Semeins, C., Ajubi, N., Frangos, J., Nijweide, P. & Burger, E. (1995). Sensitivity of osteocytes to biomechanical stress in vitro. *The FASEB Journal*, 9: 441-445.

Kruse, K. & Kracht, U. (1986). Evalution of serum osteocalcin as an index of altered bone metabolism. *European Journal of Pediatrics*, 145:27-33.

Lanyon, L. & Rubin, C. (1984). Static vs. Dynamic loads as an influence on bone remodelling. *Journal of Biomechanics*, 17: 897-905.

Leuken, S., Arnaud, S., Taylor, A. & Baylink, D. (1993). Changes in markers of bone formation and resorption in a bed rest model of weightlessness. *Journal of Bone and Mineral Research*, 8(12): 1433-1438.

Lotz, J., Steeger, D., Ehrenthal, W., Heine, J. & Prellwitz, W. (1995). Biochemical bone markers compared with bone density measurement by dual energy X-ray absorptiometry. *Calcified Tissue International*, 57: 253-257.

McCann, D., Kirkish, L., Thompson, N., Rigg, G., Hakim, M. & Guire, K. (1986). An evaluation of RIA-kit technology for serum and plasma parathyroid hormone determinations. *Journal of Clinical Immunoassay*, 9(4): 193-199.

Nichols, D., Sanborn, C., Bonnick, S., Ben-Ezra, V., Gench, B. & DiMarco, N. (1994). The effects of gymnastics training on bone mineral density. *Medicine and Science in Sports and Exercise*, 26(10): 1220-1225.

Peck, W. (1986). Bone and Mineral Research /4: A yearly survey of developments in the field of bone and mineral metabolism. Elsevier Science Publishers, Amsterdam: 103-129.

Price, J., Jackson, B., Wilson, A., Russel, R., Lanyon, L. & Goodship, A. (1995). The response of the skeleton to physical training: A biochemical study in horses. *Bone*, 17(3): 221-227.

Rubin, C., Lanyon, L. (1984). Regulation of bone formation by applied dynamic loads. *Journal of Bone Joint Surgery*, 66A: 308-314.

Slemenda, C. & Johnston, D. (1993). High intensity activities in young women: site specific bone mass effects among female figure skaters. Bone and Mineral, 20: 125-132.

Skerry, T., Bitenky, L., Chayen, J. & Lanyon, L. (1989). Early strain-related changes in enzyme activity in osteocytes following bone loading *in vivo*. *Journal of Bone Mineral Research*, 4: 793-788.

Wolman, R., Faulmann, L., Clark, P., Hesp, R. & Harries, M. (1991). Different training patterns and bone mineral density of the femoral shaft in elite, female athletes. *Annals of the Rheumatic Diseases*, 50: 487-489.

Table 6.1 Descriptive Characteristics of the Four Technical Calibres of Figure Skaters. Values are resported as Means ± Standard Deviations.

Group Characteristics	Juvenile	Novice	Junior	Senior
Subject Population (n)	7	16	22	10
Height (cm)	138.4 ± 8.3	154.7 ± 7.8	164.2 ± 8.1	171.2 ± 13.7
Body Mass (kg)	32.5 ± 7.3	45.2 ± 8.1	57.0 ± 10.8	61.4 ± 10.7
Age at Test (yr)	10.5 ± 1.5	13.4 ± 1.4	16.0 ± 1.9	21.6 ± 2.9
Maturity Index	1-2	2-3	3-4	5

Table 6.2 Intra Assay Coefficients of Variation (%CV)

Biochemical Assay	Sample (n)	Mean Value	%CV
PTH	n = 20	26 pg/ml	3.6 ± 0.9
Osteocalcin	n = 25	n/a	4.2 ± 1.2
25 Hydroxy vit D	n = 20	9.6 ng/ml	5.56 ±0.53
PICP	n = 16	54 ng/ml	3.1 ± 1.67
ICTP	n = 12	3.8 μg/L	6.2
Calcium	n = 25	2.67 mmol/L	1.1 ± 0.03

Reported by INCSTAR Inc.

Table 6.3 Coefficients of Variation (%CV) reported on duplicate samples

Biochemical Assay	Sample (n)	Mean Value	%CV
PTH	n = 55	pg/ml	< 16.4 %
Osteocalcin	n = 55	ng/ml	< 15.3 %
25 Hydroxy vit D	n = 55	ng/ml	< 13.9 %
PICP	n = 55	ng/ml	<12.7 %
ICTP	n = 55	μg/L	< 10.6 %

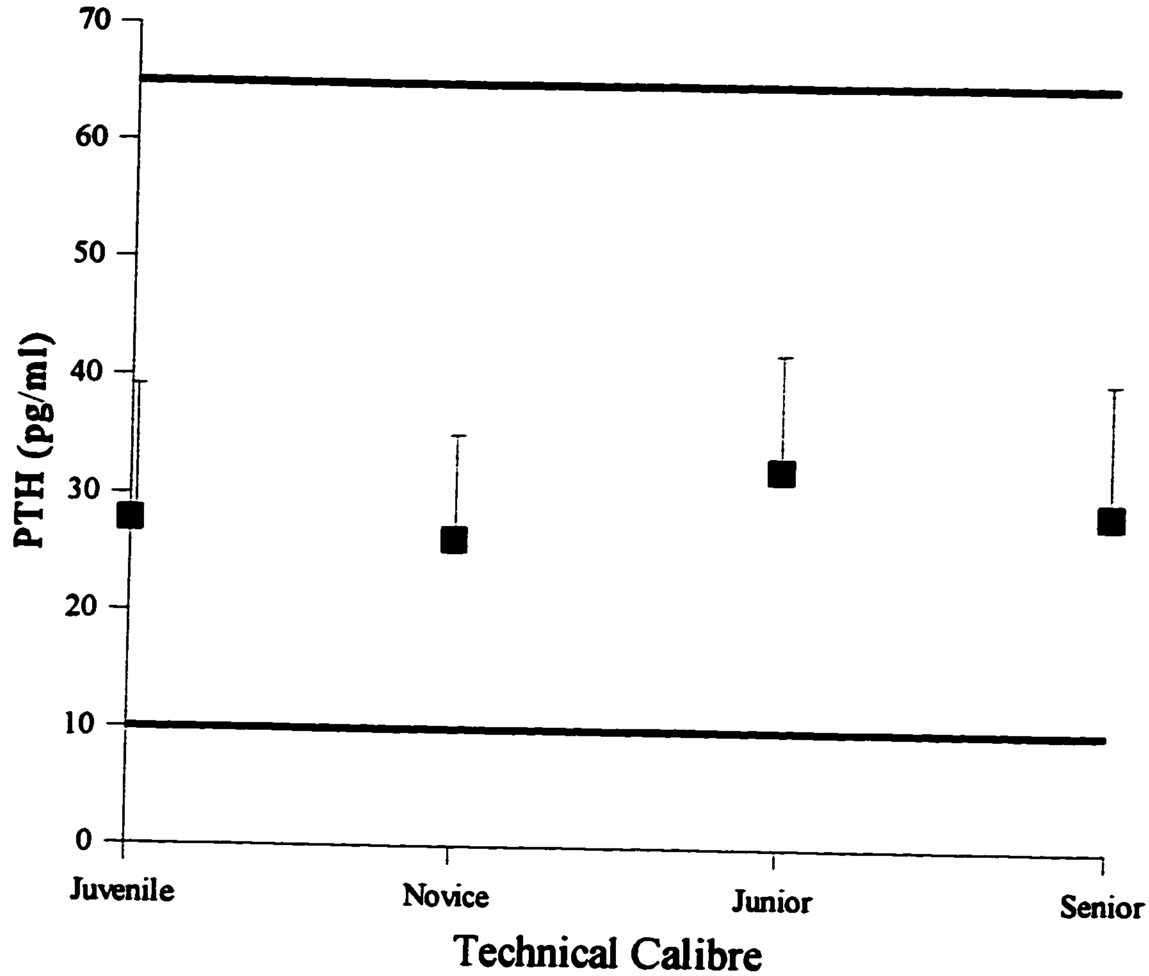


Figure 6.1 Technical calibre of skater versus serum levels of PTH pg.ml^{-1}. [a] Solid lines represent normative range values for both children and adults. No significant differences were found between groups. Values are reported as Mean ± Standard Error.

[a] Teitz Directory (1990). Clinical Guide to Laboratory Tests (2nd Edition).

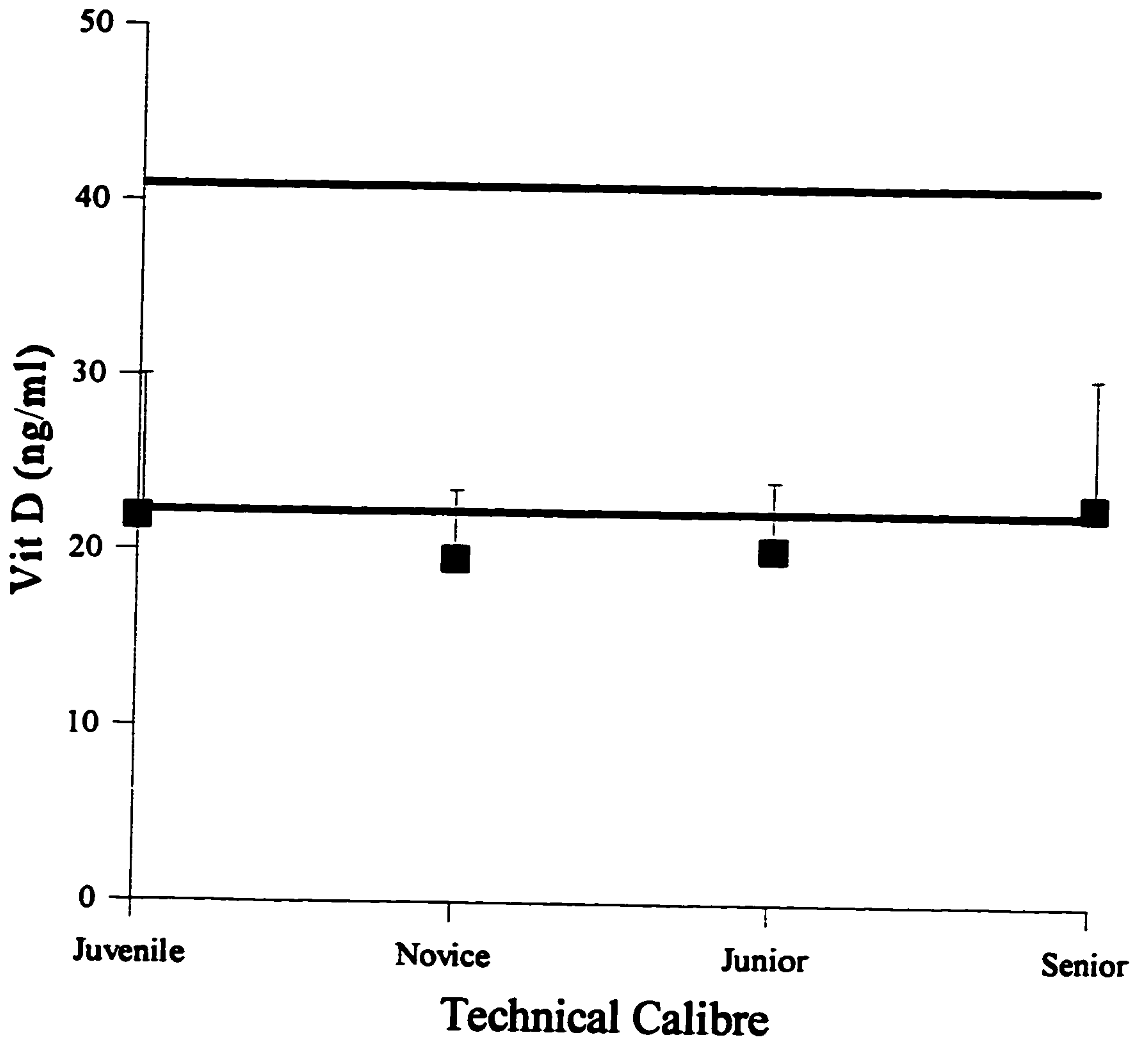


Figure 6.2 Technical calibre of skater versus serum levels of 25-hydroxy vitamin D ng.ml^{-1}.[a] Solid lines represent normative range values for both adults and children. No significant differences were found between the groups. Values are reported as Mean ± Standard Error.

[a] Teitz Directory (1990). Clinical Guide to Laboratory Tests (2nd Edition).

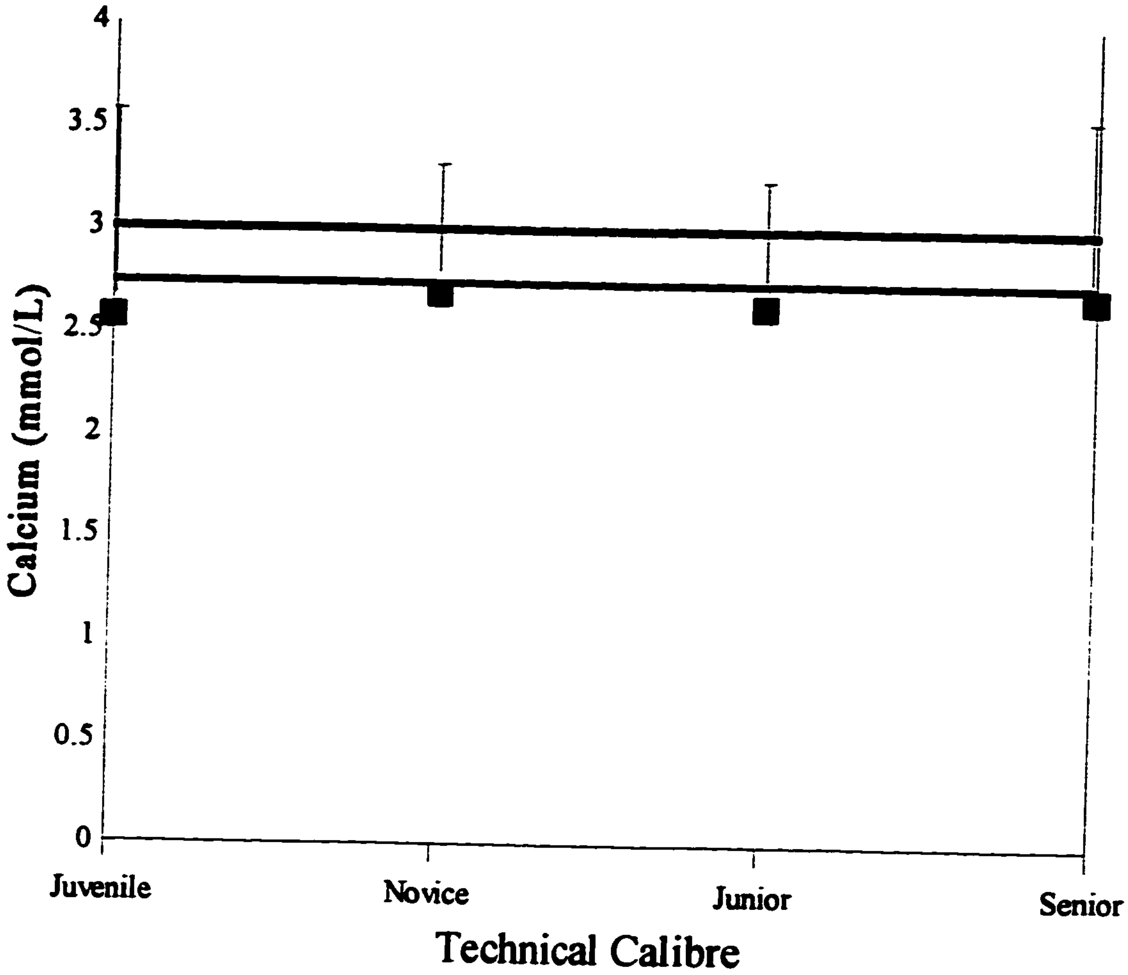


Figure 6.3 Technical calibre of skater versus serum levels of Calcium mmol.L^{-1}. [a] Solid lines represent normative range values for children and adolescents.
No significant differences were found between groups.

[a] Tietz Directory (1990). Clinical Guide to Laboratory Tests (2nd Edition).

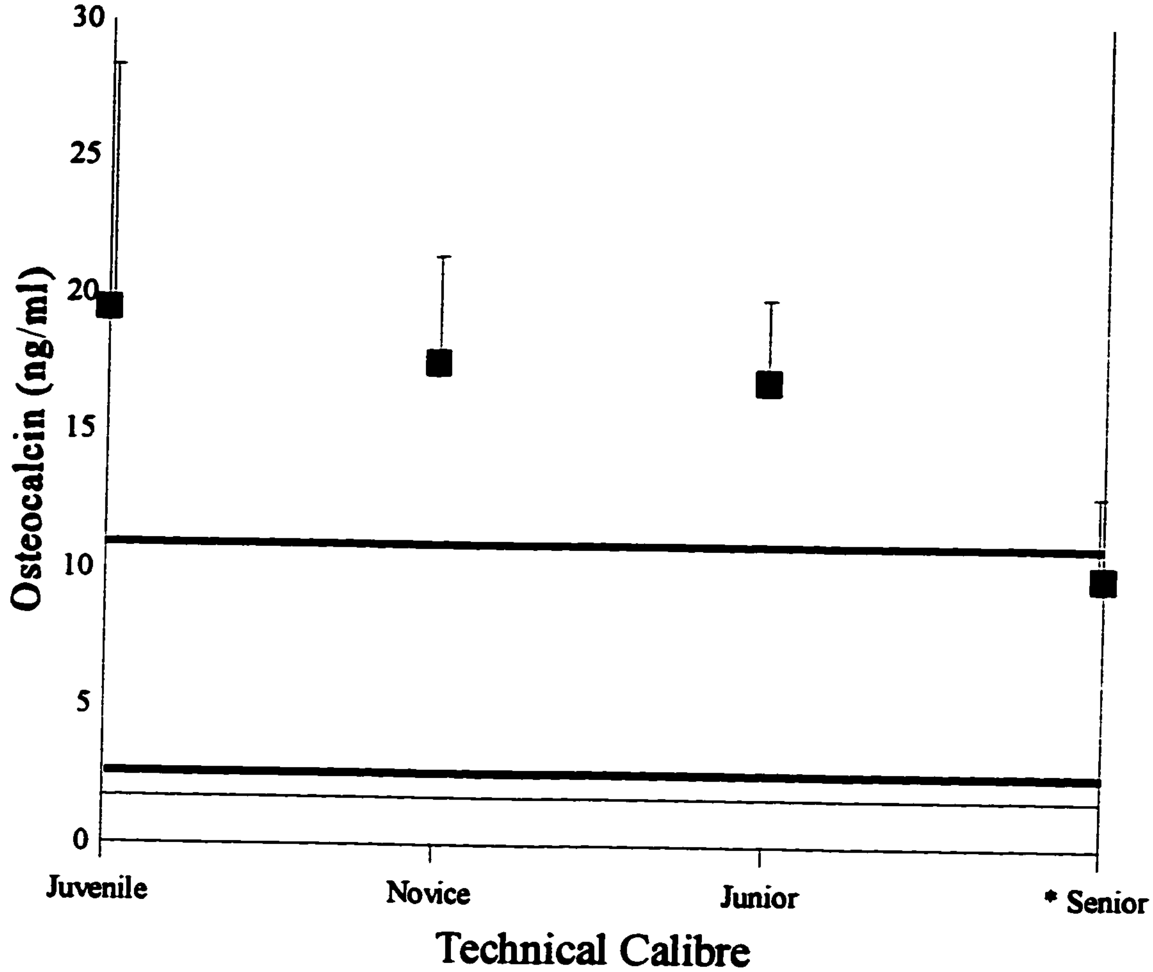


Figure 6.4 Technical calibre of skater versus serum levels of osteocalcin ng.ml $^{-1}$. [a] Solid lines represent normative range values for children and adolescents. Values are reported as Mean ± Standard Error.

* Seniors were significantly different than other three calibres of skaters ($p \leq 0.05$).

[a] Tietz Directory (1990). Clinical Guide to Laboratory Tests (2nd Edition).

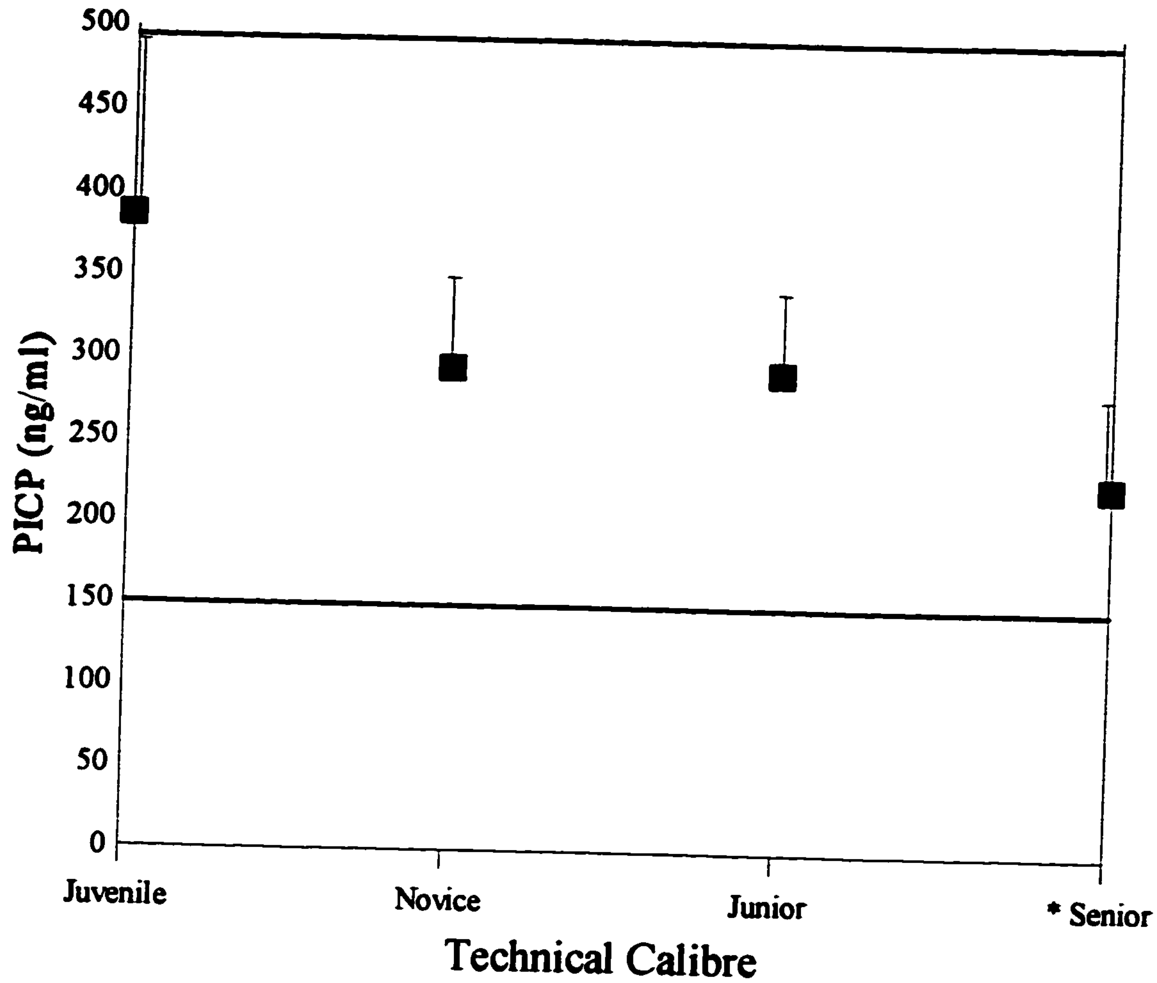


Figure 6.5 Technical calibre of skater versus serum levels of PICP ng.ml^{-1} . [a] Solid lines represent normative range values for both children and adolescents. Values are reported as Mean ± Standard Error.

* Seniors were significantly different than other calibres of skaters ($p \leq 0.05$).

[a] Tietz Directory (1990). Clinical Guide to Laboratory Tests (2nd Edition).

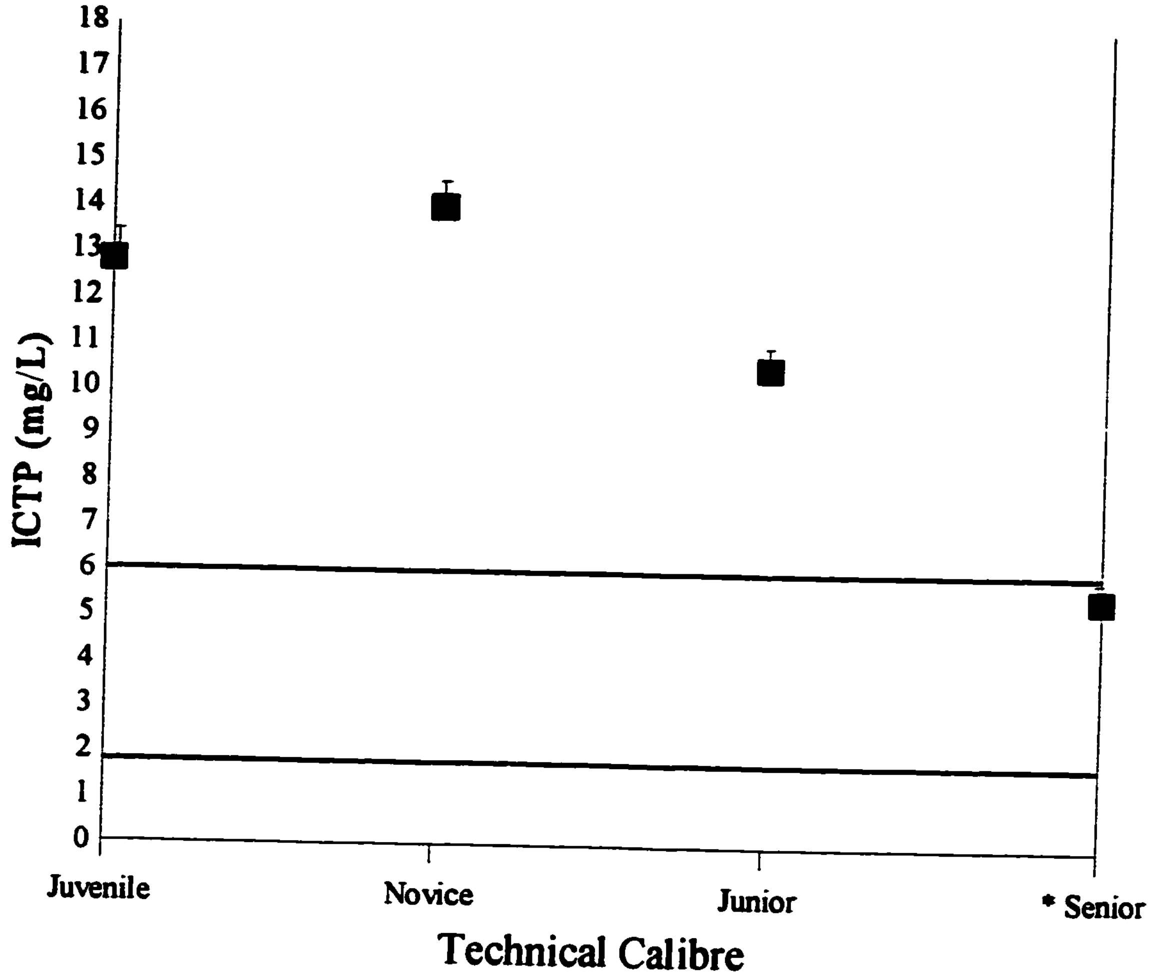


Figure 6.6 Technical calibre of skater versus serum levels of ICTP mg.L^{-1}. [a] Solid lines represent normative range values for adults ages 30-60 years. Values are reported as Mean ± Standard Error.

* Seniors were significantly different from other calibres of skaters ($p \leq 0.05$).

[a] Tietz Directory (1990). Clinical Guide to Laboratory Tests (2nd Edition).

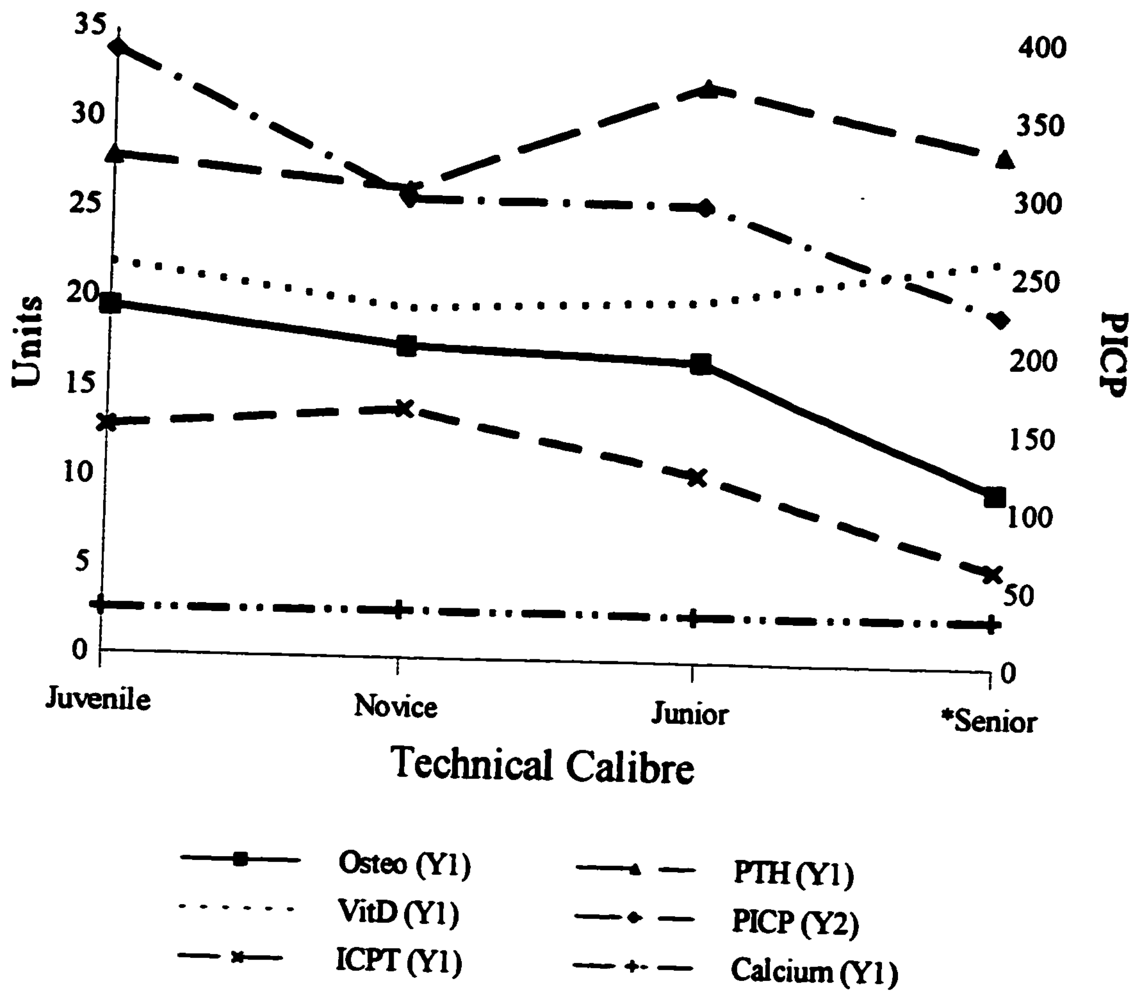


Figure 6.7 Trends of six biochemical markers of bone turnover in four successive technical calibres of competitive figure skaters. Values are reported as Mean ± Standard Error.

* Statistically significant difference observed in serum values of osteocalcin, PICP, and ICTP ($p \leq 0.05$).

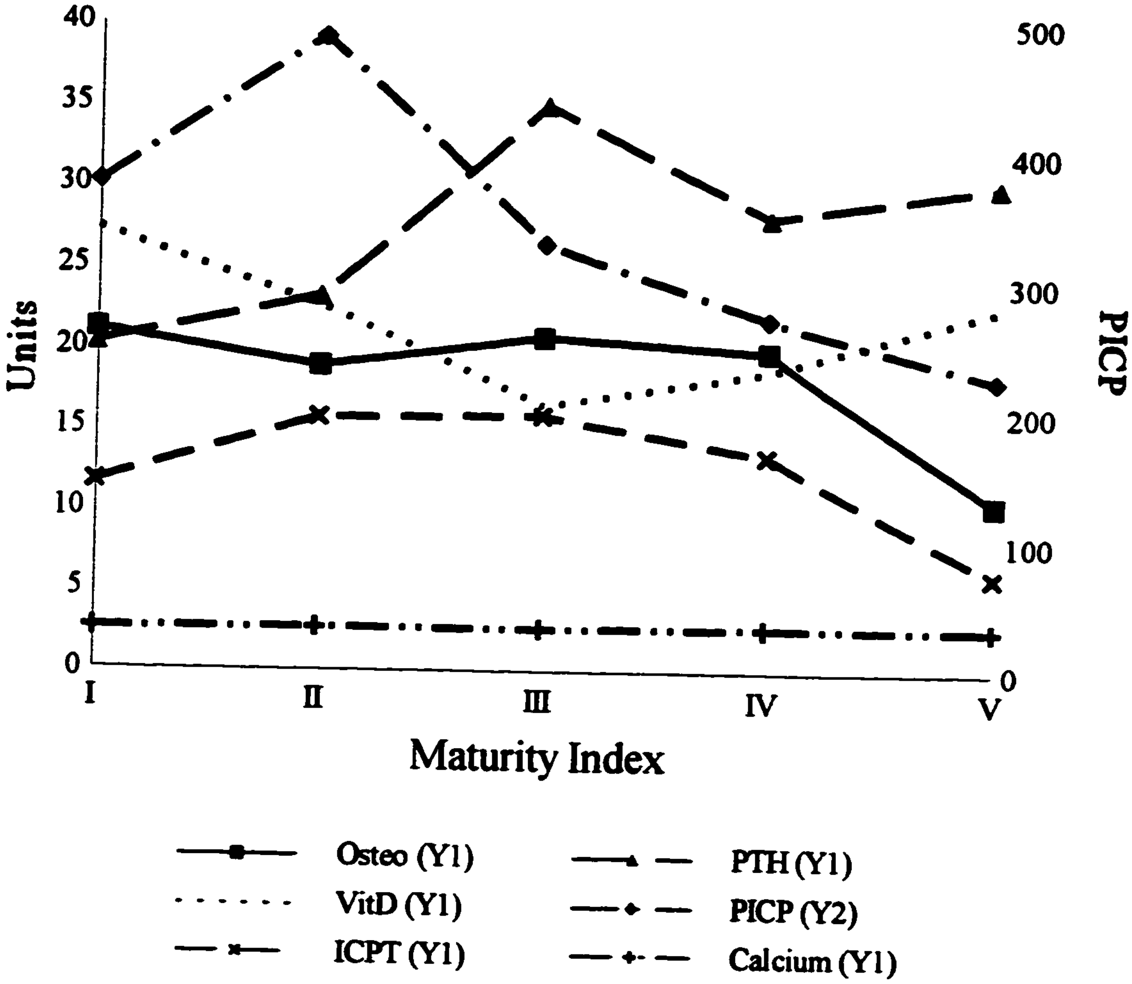


Figure 6.8 Trends of six biochemical markers of bone turnover in five stages of maturity index of competitive figure skaters. Values are reported as Mean ± Standard Error.

* Statistically significant difference observed in serum values of osteocalcin, PICP, and ICTP ($p \leq 0.05$).

CHAPTER SEVEN

Summary Analysis

RELATIONSHIPS

GENERAL DISCUSSION & CONCLUSIONS

Introduction

During the last decade, the sport of figure skating has made remarkable advances in technique and subsequent skill level of the performing athletes. On-ice jumping has been touted as the technical element of competition. Competitive figure skaters at a national level are currently executing six triples and potentially quadruple revolution jumps in a 4 ½ minute free skating program. This trend has forced coaches and athletes to focus their attention and energy on mastering these difficult tasks early in a skater's competitive career. Training the successful execution and landing of single, double, triple, and potentially quadruple revolution jumps has placed increased physical demands upon these athletes, especially in terms of impact absorption. The question of whether the musculo-skeletal system of younger athletes is sufficiently mature or strong enough to endure the stresses of this type of training has arisen, with the primary concern being the potential for impact related skeletal injuries. Whether or not there is a sufficient adaptive process as a result of training to provide a protective mechanism for these young bodies is also unknown. Although recent review articles (Chilibeck *et al.*, 1995; Bailey, 1994; Forwood & Burr, 1993; Heinonen *et al.*, 1993; Suominen, 1993; Grimston *et al.*, 1992; Ott, 1991; Smith & Gilligan, 1991; Bailey & McCulloch, 1990) have cited a plethora of studies that conclude that musculo-skeletal stress, such as enhanced physical activity or mechanical loading, may stimulate bone growth and peak bone mass attained in younger years and is a crucial consideration in the preservation of skeletal integrity in later years, there is evidence that intense impact loading may also have a negative influence on bone health (Bailey *et al.*, 1989; Forwood & Burr, 1993; Grimston *et al.*, 1993; Robbins & Gouw, 1990; Lanyon, 1986). It has been reported by Bailey *et al.* (1989) that there is a temporary increase in the porosity of bone during the period of most rapid growth in adolescents, which may potentially be responsible for an increased incidence of fracture during growth. These findings were not solely explained by an increase in physical activity, however they would provide evidence that an impact loaded group may be at further risk, given the state of bone during maturation.

Related research conducted specifically in the sport of figure skating is scarce, with only a single article identified (Slemenda & Johnston, 1993). However, young athletes training in competitive sports also containing a repetitive, high impact component, such as gymnastics, have been the focus of recent investigations (Kirchner *et al.*, 1995; Robinson *et al.*, 1995; Nichols *et al.*, 1994; Grimston *et al.*, 1993). Researchers (McNitt-Gray, 1991; Dufek & Bates, 1991) have suggested that landings account for the highest incidence of injury in impact related sports, such as gymnastics, and the potential for injury was the highest in the lower extremities in comparison to other parts of the body. Grimston & Zernicke (1993) confirmed these earlier findings and associated the prevalence of exercise-induced stress responses of bone in athletic populations with impact activities and identified unwise training practices as a precipitating factor. In this regard, there was a need for an in depth study to investigate the effects that repetitive impact load-type training in competitive figure skaters has upon skeletal integrity. This series of six studies was undertaken to gain further insight into the interaction of major factors in response to repetitive impact loading. The purpose was to provide a comprehensive profile of individuals who have a history of and are currently training in intensive, repetitive impact activity and further characterize the potential responses of impact load-type training. It was proposed that from the collective results of these projects a comprehensive profile of athletes who have been subjected to repetitive impact load-type training could be developed. Results would allow insight into whether this type of training or mechanical usage (ie., impact loads) elicits physiological responses, biochemical fluctuations, and/or bone mineral density measures beyond normative values. Potential risks or benefits associated with impact load-type training may also be speculated. Subsequently, new coaching strategies and training guidelines may be developed, thereby enhancing training and the long-term bone health of these athletes.

Relationships

The relationships between the independent variables (gender, technical calibre and maturation), and important dependant variables (physiological fitness measures, bone mineral values, biochemical markers, training and nutritional data) were determined by a Pearson product moment correlation analyses ($p \leq 0.05$). As may be expected, significant relations were observed among several of the variables examined (Table 7.1), therefore the data were presented as a continuum of responses with respect to level of impact training, maturation, and gender. All factors investigated have been previously shown as having independent and/or combined effects on bone mineral measures or bone turnover (Chapter II).

A strong correlation existed between technical calibre of skater, defined as juvenile, novice, junior and senior, and maturity index defined by a self reported account of five stages of development (Bailey *et al.*, 1994) ($r = 0.77$, $p \leq 0.05$). This relationship was paralleled by chronological age (yrs), height (cm), body mass (kg), and duration of competitive training (yrs). Older skaters were developmentally more mature, taller and heavier, had been training within the sport of figure skating for a longer period of time and as a result were technically more advanced. The subsequent relations of calibre and maturation with the other dependent variables examined were analogous. With the exception of VO_2 max (ml/kg/min), calibre and maturation were both positively related to all the physiological measures selected as performance determinants: two foot vertical jump (cm), one foot vertical jump (cm) and relative peak power (w/kg) ($p \leq 0.05$). Calibre was only moderately associated with VO_2 max (ml/kg/min) ($r = 0.49$, $p \leq 0.05$), and maturation did not reach statistical significance. However, when VO_2 max was expressed in absolute terms (L/min), significant correlations with both technical calibre ($r = 0.77$, $p \leq 0.05$) and maturation ($r = 0.69$, $p \leq 0.05$) were revealed. No significant associations were observed among calibre or maturation and measures of body fat (%) and flexibility (cm), respectively. Strong positive correlations were revealed among both technical calibre and maturation, and bone mineral values of the impact absorbing sites examined. In contrast, significant negative relations were observed between BMD and the selected biochemical markers of bone turnover (osteocalcin, PICP, and ICTP) ($p \leq 0.05$).

Sex was positively correlated with all variables examined with the exception of body fat (%), flexibility, and BMD measures of the lumbar spine and left Ward's triangle. Males assessed in this study were generally taller, weighed more, had a lower percentage body fat, were less flexible, and had accumulated higher BMD at selected sites. However, due to a scarcity of young males in competitive figure skating, males were under represented in the pre-pubescent groups (maturity index I & II) of this investigation and therefore results of gender specific differences were interpreted with caution.

All physiological variables examined were significantly correlated with years of competitive training. This may support the positive influence of the sport specific training on the physiological profiles of these athletes. Height (cm), body mass (kg), one and two foot vertical jumps (cm) and relative peak power (w/kg) were positively related to bone mineral measures and negatively associated with biochemical markers ($p \leq 0.05$). These associations parallel those stated previously with calibre and maturation. Body mass has been proven to strongly influence bone mineral measures (Bailey, 1995). In the current group of studies, correlation coefficients ranging from 0.65 - 0.89 ($p \leq 0.05$) were computed between bone mineral values at selected impact loaded sites and body mass. The mechanical loading characteristics of both vertical jump measurements and power calculations may have contributed to the strong correlation with bone mineral values at the weight bearing sites assessed. Relative measures of VO_2 max (ml/kg/min) did not correlate with BMD of the lower extremities, however moderate to strong associations existed when VO_2 max was presented as an absolute value (L/min) ($r = 0.59$-0.92, $p \leq 0.05$). This data is somewhat consistent with the results of Pocock *et al.* (1986), who demonstrated that cardiovascular fitness was a significant predictor of BMD of regions of the proximal femur, however the results of the present study would appear to favour the influence of mechanically loaded variables in comparison.

The consistent negative relationship observed among biochemical indices and technical calibre, maturity, years of competitive training, physiological measures and bone mineral values may be explained by the parallel nature of these variables. With years of experience, skaters age with advanced technical training, their physiological profiles are further developed, and the mechanical loading characteristics of their training becomes more intense. Furthermore in these analyses, all of these variables paralleled maturation. As a individual reaches maturation, bone turnover is depressed. Therefore it may be expected that as all subsequent variables increase, markers of bone turnover would decrease.

Nutrition has been cited as a major determinant of peak bone mass, with calcium as the most important nutrient (Welten *et al*, 1994), however this relationship has not been supported by consistent evidence. On the average, the skaters in this study reported a dietary calcium intake within or in excess of the Canadian Recommended Nutritional Intakes (RNI) for their respective age groups. Serum calcium was also within recommended range for their respective ages. Although it has been suggested that childhood and adolescent years are the most important in terms of the influence of calcium on bone status, calcium has been proposed as a threshold nutrient with an abundance giving minimal advantage over the recommended threshold (Bell, 1983). In the present analysis, no significant relationships were found between dietary calcium or serum calcium and any other variables. In agreement with the data presented, Welten *et al.* (1994) reported high correlations between body weight, physical activity and their collective effects on BMD. However, this latter study did not find that calcium was a predictor of BMD. More research may be recommended to clarify the duration and intensity of calcium loading and the calcium intake required to maximize bone status in the growth years.

General Discussion & Conclusions

The kinetic and kinematic data presented in Chapter III confirmed the impact nature of on-ice jumping. Measurements of foot pressures provided insight into the dynamics of the landing phase and the analysis of movement upon impact provided information regarding how the body absorbs the impact. From this data, it was suggested that figure skating imposes a high impact stress on the participants. The magnitude of impact and pattern of stress (eg., increased volume, frequency and intensity) was clearly identified as increasing with technical calibre of skaters. Impact damping took place mainly at the knee and hip joints with minimal contribution by the ankle joint. These biomechanical observations not only provided insight on the impact forces and techniques used by the competitive figure skaters to absorb landing forces but also serves as a data base to relate other physiological, bone mineral density, and biochemical alterations proposed as a result of impact training. Furthermore, this data base could possibly be used as a model in other impact related sports.

Historically, it has been suggested that from a growth and developmental perspective, there has been more concern with too much rather than too little mechanical loading (Bailey, 1995). From the child workers of the early industrial revolution who experienced a stunting of growth to a more recent study investigating the detrimental effects of intensive mechanical loading on growth in competitive gymnasts (Theintz et al., 1993), concerns have arisen. However the results of the present series of investigations do not support these negative consequences of impact load-type training in figure skaters. With advancing calibre and maturation, both the physiological and bone mineral profiles of these athletes were enhanced. The physiological profiles of the four successive technical calibres of skaters studied revealed a linear increase, paralleling growth and maturation. BMD and BMC also increased with advanced technical calibre, maturation, and physiological fitness level. In comparison to non trained controls, the BMD of the skaters were consistently higher. It was speculated that this relationship may have been reversed if impact load-type training, as experienced by competitive figure skaters, had a detrimental effect on bone, Therefore, these data appear to support the positive outcomes associated with training inherent in the sport of figure skating.

As stated by Bailey (1995), childhood activities that preferentially stress one side of the body over the other provide the strongest evidence that physical activity can modulate bone mineral density during the growing years over and above genetic considerations. The focus of the cross sectional study presented in Chapter V was to determine whether a contra lateral training regime consisting of repetitive weight bearing impacts would be reflected in BMD. Not only were the lower extremity BMD values obtained from the impact loaded group significantly greater than the controls, the landing leg or dominant limb of the figure skaters measured greater BMD than their respective contra lateral limb. Although a causative relationship between sport training and BMD cannot be clearly definitive, the observed trends may have clinical significance. In contrast to biases that may exist in cross sectional studies suggesting that participants involved in impact related activities may be a product of sport selection, having a higher BMD or BMC initially, a contra lateral research design reduces this potential assumption.

The biochemical profiles illustrated elevated levels of bone turnover in the pre-pubescent and pubescent groups. Increased levels of bone turnover at this time are representative of bone growth, mineral accretion, and also bone modelling. Upon reaching maturity (maturity index V), levels were significantly lower indicating a depression in bone turnover once final size, shape, and density of bone had been achieved. Similar to the bone mineral measures, if impact load-type training had a negative effect on bone, turnover may have been depressed during peak growth periods or in contrast, may have remained elevated after maturity indicating a repair process occurring due to a breakdown. The data presented as result of this study did not appear to support a negative influence however, due to the lack of a control group a conclusion here is difficult.

A major limitation of this series of investigations was the lack of a consistent control group. As a result, a significant proportion of the data presented can only be descriptive in nature. Furthermore, the small sample size allowed analysis of only linear relationships of the variables examined. However, descriptive, cross sectional studies when carefully analysed can be used to direct future longitudinal research. A longitudinal study tracking these athletes in comparison to tracking a normative control group would allow further insight into the differing responses. Following athletes that have retired from the sport or through an injury from diagnosis to clinical recovery would also allow further insight into the long term and lasting effects of impact loading on bone.

The major advantage of this research in comparison to similar BMD related research was the depth of investigation. Few studies have quantified the impact of activity, in addition to thoroughly investigating the responses from an interdisciplinary perspective. This series of investigations presents an overview of integrated profiles of impact-trained, figure skaters, at varying levels of technical proficiency and maturation. In conclusion, it may be suggested that the significant correlations between the variables examined and their parallel associations confirmed a balanced development of the physiological, biochemical, and bone mineral profiles of these athletes. It may be recommended that the knowledge gained be used as criteria to monitor and guide the development of other athletes. A normative data base for this specific population may be of benefit to disseminate to the National Sport Governing bodies where impact provides a basis for training in their respective sports.

References

Bailey, D. (1995). The role of mechanical loading in the regulation of skeletal development during growth. In C. Blimkie & O. Bar-Or (eds), *New Horizons in Pediatric Exercise Science*, Human Kinetic Publishers, Champaign, Il.: 97-108.

Bailey, D. (1994). Invited Paper: Physical activity and the attainment of peak bone mass in children. *The Australian Journal of Science and Medicine in Sport*, 26(½):3-5.

Bailey, D., McKay, H., Faulkner, R. & Drinkwater, D. (1994). A non-invasive method for determining maturational status in adolescent boys and girls in longitudinal investigations. *Canadian Journal of Applied Physiology*, 19 (Suppl): 3P.

Bailey, D. & McCulloch, R. (1990). Bone Tissue and Physical Activity. *Canadian Journal of Sport Sciences*, 15(4): 229-239.

Bailey, D., Wedge, J., McCulloch, R., Martin, A. & Bernhardson, S. (1989). Epidemiology of fractures of the distal end of the radius in children as associated with growth. *Journal of Bone and Joint Surgery*, 71A (8): 1225.1230.

Bell, N. (1983). Normal physiology of calcium homeostasis. *American Association for Clinical Chemistry*, 2(3), September: 1-12.

Chilibeck, P., Sale, D. & Webber, C. (1995). Exercise and bone mineral density. *Sport Medicine*, 19(2): 103-122.

Dufek, J. & Bates, B. (1991). Biomechanical factors associated with injury during landings in jump sports. *Sports Medicine*, 12(5): 326-337.

Forwood, M. & Burr, D. (1993). Physical activity and bone mass: exercises in futility? *Bone and Mineral*, 21: 89-112.

Grimston, S., Willows, N. & Hanley, D. (1993). Mechanical loading regime and its relationship to bone mineral density in children. *Medicine & Science in Sports & Exercise*, 25(11): 1203-1210.

Grimston, S., Morrison, K., Harder, J. & Hanley, D. (1992). Bone mineral density during puberty in Western Canadian children. *Bone & Mineral*, 19: 85-96.

Grimston, S. & Zernicke, R. (1993). Exercise-related stress responses in bone. *Journal of Applied Biomechanics*, 9: 2-14.

Heinonen, A., Oja, P., Kannus, P., Sievanen, H., Manttari, A. & Vuori, I. (1993). Bone mineral density of female athletes in different sports. *Bone & Mineral*, 2: 1-14.

Kirchner, E., Lewis, R. & O'Connor, P. (1995). Bone mineral density and dietary intake of female college gymnasts. *Medicine & Science in Sports and Exercise*, 27: 496-502.

Lanyon, L. (1986). Biomechanical factors in the adaptation of bone structure to function. In: Uhthoff, H. and Stahl, E. (ed.), *Current Concepts of Bone Fragility*, Berlin, Springer-Verlag: 19-33.

McNitt-Gray, J. (1991). Kinematics and impulse characteristics of drop landings from three heights. *International Journal of Sport Biomechanics*, 7: 201-224.

Nichols, D., Sanborn, D., Bonnick, S., Ben-Ezra, V., Gench, B. & Dimarco, N. (1994). The effects of gymnastics training on bone mineral density. *Medicine and Science in Sports and Exercise*, 26(10): 1220-1225.

Ott, S. (1991). Bone density in Adolescents. *The New England Journal of Medicine*, 325(23): 1646-1647.

Pocock, N., Eisman, J., Gwinn, T., Sambrook., P., Kelly, P., Freund, J. & Yeates, M. (1986). Muscle strength, physical fitness and weight but not age predict femoral neck bone mass. *Journal of Bone and Mineral Research*, 4: 441-448.

Robbins, S. & Gouw, G. (1990). Athletic footwear and chronic overloading. *Sports Medicine*, 9: 76-85.

Robinson, T., Snow-Harter, C., Taaffee, D., Gillis, D., Shaw, J. & Marcus, R. (1995). Gymnasts exhibit higher bone mass than runners despite similar prevalence of amenorrhea and oligomenorrhea. *Journal of Bone and Mineral Research*, 10(1): 26-35.

Slemenda, C. & Johnston, D. (1993). High intensity activities in young women; site specific bone mass effects among female figure skaters. *Bone and Mineral*, 20: 125-132.

Smith, E. & Gilligan, C. (1991). Physical activity effects on bone metabolism. *Calcification Tissue International*, (Suppl..), 49: S50-S54.

Suominen, H. (1993). Bone mineral density and long term exercise: An overview of cross-sectional athlete studies. *Sports Medicine*, 16(5): 316-330.

Tanner, J. (1962). Growth at Adolescence (2nd ed.). Oxford, Blackwell.

Theintz,G, Howald, H., Weiss, V., Sizonenko, P. (1993). Evidence for a reduction of growth potential in adolescent female gymnasts. *Journal of Pediatrics*, 122: 306-313.

Welten, E., Kemper, H., Post, G., Mechelen, W., Twist, J., Lips, P. & Teule, G. (1994). Weight bearing activity during youth is a more important factor for peak bone mass than calcium intake. *Journal of Bone and Mineral Research*, 9(7):1089-1096.

Table 7.1 Correlation Matrix. Only significant values have been shown (p≤ 0.05).

				Physiological Variables							Bone Mineral Density (BMD grams/cm²)					Biochemical Indices			Training Variables	
	Calibre	Gender	Maturity	Body Mass	Height	Body Fat	1 Ft. VJ	2 Ft. VJ	Power	VO_2 max	L1-L4 BMD	Rt. Total Hip BMD	Lt. Total Hip BMD	Rt. Wards BMD	Lt. Wards BMD	Os	PICP	ICTP	Starting Age	Yrs. of Training
Calibre	1	.42	.77	.70	.70	--	.62	.72	.74	.49	.67	.80	.75	.68	.52	-.37	-.30	-.49	--	.68
Gender		1	--	.40	.48	-.42	.49	.52	.52	.63	--	.43	.37	.30	--	--	--	--	--	.34
Maturity			1	.76	.70	--	.52	.62	.70	--	.76	.76	.71	.64	.55	-.50	-.54	-.62	--	.67
Physiological:																				
Body Mass (kg)				1	.91	--	.71	.72	.74	--	.85	89	.84	.89	65	-.54	-.40	-.62	--	.70
Height (cm)					1	--	.75	.75	.72	.30	.70	.80	.73	.64	.54	-.36	-.32	-.46	--	.61
% Body Fat						1	--	-.34	--	-.69	--	--	--	--	--	--	--	--	--	--
1 Ft. Vertical Jump							1	.87	.72	.48	63	.73	.67	.58	.50	-.44	-.35	-.53	--	.65
2 Ft. Vertical Jump								1	.60	.40	.57	.67	.63	.49	.44	-.38	--	-.48	--	.64
Rel. Peak Power									1	.48	58	.78	.71	.71	.63	-.36	--	-.45	--	.71
VO_2 max										1	--	.42	.35	--	--	--	--	--	--	.37
BMD:																				
L1-L4 BMD											1	.83	.83	.75	.64	-.60	-.55	-.64	--	.62
Rt. Total Hip BMD												1	.95	.88	.77	-.49	-.42	-.58	--	.75
Lt. Total Hip BMD													1	.88	.84	-.46	-.43	-.54	--	.64
Rt. Wards BMD														1						
Lt. Wards BMD															1					
Biochemical:																				
Osteocalcin																1	.63	.88	--	-.59
PICP																	1	.62	--	-.35
ICTP																		1	--	-.58
Training:																				
Starting Age																			1	-.34
Yrs. Of Training																				1

APPENDICES

Chapter Two

Appendix A	*Bone Mineral Density Studies in Sport*
Appendix B	*Normative Data - Bone Mineral Density Studies on Children*
Appendix C	*Bone Mineral Density on Children in Sport*
Appendix D	*Normative Ranges for Biochemical Markers*

Chapter Three

Appendix E	*Subject Informed Consent Form*

Chapter Four

Appendix F	*A Non-invasive Method for Determining Maturational Status in Children and Adolescents*
Appendix G	*Calcium Food Frequency Questionnaire*
Appendix H	*Activity Inventory Questionnaire*
Appendix I	*Menstrual History Questionnaire*

Chapter Five

Appendix J	*Subject Informed Consent Form*
Appendix K	*Bone Mineral Density Assessment Protocols*

Appendix A

Bone Mineral Density Studies in Sport

Author (year)	N(Subjects) N (Controls)	Gender (Age)	Activity Type (Duration)	Measurements Bone Scan	 Site	Assessments Diet	 Maturity	Results
Fehling et al., 1995	28 13	F	Gymnasts Volleyball Swimmers	DEXA	Lumbar Spine Proximal femur Total Body		Menstrual History Body Comp.	↑ BMD in athletes in impact sports Differences tend to be site specific No difference between swimmers & controls
Friedlander et al., 1995	127	F(20-35)	Aerobics Weight Training Stretching (2 Years)	QCT DXA SPA	Spinal Trabecular BMD Spine Lateral Spine Femoral Neck Trochanter BMD Calcaneal BMD	Ca Suppl.. (+1500 mg/day)		Significant gain in BMD in exercise group No effect of Ca supplement on BMD
Heinonen et al., 1995	59 25	F(21.4-28.3) F(23.8± 4.7)	Squash Aerobics Speed Skaters Physically Active	DEXA	L2-L4 Femoral Neck Distal Femur Patella Proximal Tibia Calcaneus Distal Radius	7 day Ca Intake	Menstrual Status	Squash players had highest BMD in all sites Site specific ↑ seen in specific activities Physically active no different than controls
Kirchner et al., 1995	26 26	F(± 1.0)	Gymnasts	DEXA	L1-L4 Proximal Femur Femoral Neck Ward's Δ Whole Body BMD	Food Frequency Questionnaire EDI-2 Questionnaire	EDI-SC Ques. Menstrual Status	No diff. in age, ht., wt. Gymnasts leaner than controls Activity level was sign. different ↑ BMD at all sites in gymnasts No diff. between OC users and non No diff. in diet, except CHO ↑ incidence of menstrual disturbance in gymnasts

Continued

Author (year)	N(Subjects) N (Controls)	Gender (Age)	Activity Type (Duration)	Measurements Bone Scan	Site	Assessments Diet	Maturity	Results
Lohman et al., 1995	22 34	F(28-39)	(18 Months)	DEXA	Total Body Lumbar Spine Femoral Neck Wards Δ Trochanter	12 day Osteocalcin Body Composition		↑ regional BMD with exercise ↑ lean body tissue with exercise No change in Total body BMD 20% ↑ in Osteocalcin with exercise
Robinson et al., 1995	21(n=19) 20	F(20.4± 2.3)	Gymnasts Runners	DXA	L2 - L4 Femoral Neck Whole body	4 day Ques.	Menstrual Stat.	↑ BMAD in lumbar spine & femoral neck of gymnasts than runners & controls ↓ BMD of whole body in runners 30% of runners oligo or ammenorrheic 47% of gymnasts oligo or ammenorrheic
Nichols et al., 1994	11(n=11)	F(21.1± 2.1)	Gymnastics 27 wk	DXA	L2-L4 Femoral Neck Ward's Triangle	3 day 1 day Bld Analysis	Menstrual Stat.	8-10% ↑ BMD in gymnasts 1.3% ↑ BMD in lumbar spine after training
Kannus et al., 1994	20(n=20)	M(19-34 yr.)	Tennis Players	DXA	Prox. Humerus Humeral Shaft Radial & Ulnar Shaft Distal Radius & Ulna Hand			↑ BMD in dominant side of tennis players Side to side differences in tennis players ranged from 14.4 -25% and in controls from 0 - 6%.
Sievanen et al., 1994	1	F(26 yr.)	Strength Trained 26 months	DXA	Lumbar Spine Lower Extremities			1.8 - 3.1% site specific ↑ in BMD
Heinonen et al., 1993	30 (n=25) 28 29 18	F (23.3±3.1) F (21.3±3.2) F (24.0±5.7) F (24.6±4.6)	Orienteers X country skiers Cyclists Weight lifters	DXA	Lumbar Spine Femoral Neck Distal Femur Patella / Prox. Tibia Calcaneus \ Distal Radius	Ca+	Menstrual Stat.	9%-26% ↑ BMD in weight lifters Weight training provided more effective osteogenic stimulus than endurance events.

Continued

Author (year)	N(Subjects) N (Controls)	Gender (Age)	Activity Type (Duration)	Measurements Bone Scan	Site	Assessments Diet	Maturity	Results
Slemenda et al., 1993	22 (n=22)	F(10-23yrs)	Figure Skaters 25-40 hr/wk	DXA	TBBMD	3 day Ca+	Menstrual Stat.	No significant ↑ BMD in upper body 5.5% & 11%↑ BMD in leg & pelvis 40% of skaters had menstrual disturbance
Grimston et al., 1991	8	F(32.8± 0.7)	Non Fracture Runners	DPA	L2-L4	Ca+	Menstrual Stat.	↑ vert. impact forces in stress fractured runners
	6	F(26.9± 3.2)	Fracture Runners		Femoral Neck Tibia diaphysis			↑ BMD in stress fractured runners
Wolman et al., 1991	67	F	Runners Rowers Dancers	DPA	Mid Femoral Shaft		Menstrual Stat.	↑ BMD in runners
McCulloch et al., 1990	101	F(20-35 yrs)	Volunteers	CT Scan	Rt. os calcis		Childhood Milk consumption Questionnaire Current Physical Act. Questionnaire	Sig. ↑ in BMD of individual whom are Physical Act. & participated in childhood sports
Snow-Harter et al., 1990	59	F(18-31yrs)	Sedentary to Active	DEXA SPA	L2 - L4 Lt. Prox. Femur Mid Radius			Muscle strength accounts for 15-20% of the variance in BMD in young females
Pirnay et al., 1987	10(n=10)	?(21.2± 1.3)	Prof. tennis players	DPA	Lt. & Rt. forearms Radius(distal diaphysis) Radius(diaphysis) Ulna			9% bone hypertrophy seen in dominant wrist of tennis players No sig. diff. between arms in control group 34% ↑ BMD in dominant arm of athletes
Margulies et al., 1986	268	M(18-21 yr.)	Physical Training for 14 wks	SPA	Lt. & Rt. Distal third of Tibia			11.1% ↑ BMD in left leg 5.2% ↑ BMD in right leg

Continued

Author (year)	N(Subjects) N (Controls)	Gender (Age)	Activity Type (Duration)	Measurements Bone Scan	Site	Assessments Diet	Maturity	Results
Nilsson et al. ,1971	11(n=39)	M(20.7± 8.4)	Weightlifters	SXA	Distal femur			↑ femoral BMD in athletic group
	4	M(23.5± 3.0)	Throwers					
	25	M(22.2±7.1)	Runners					
	15	M(24.9± 5.2)	Soccer Players					
	9	M(17.9±4.5)	Swimmers					

*TBBMD - Total Body Bone Mineral Density

Appendix B

Normative Data - Bone Mineral Density Studies on Children

Bone response specific to age/maturity

Author (year)	N	Gender (Age)	Measurements Bone Scan	Site	Assessments Activity	Diet	Maturity	Results
McKay et al., 1995	41 42	F(11.8) M(12.7)	DXA	Femoral Neck Trochanteric Region Prox. Femur				Strong familial resemblances in BMD
Zanchetta et al., 1995	433 345	F( ) M( )	DEXA	Whole Body AP & Lat Spine Radius Femoral Neck, Trochanter, Ward's Δ			Tanner Staging	Gender differences only significant after 13 years Females BMD > males 12-14 years Males BMD > females > 15 years
Kroger et al., 1992	44 40	F (6-19 yr.) M (6-19 yr.)	DXA	L2 - L4 Femoral Neck	Questionnaire	Dietary Calcium		↑ BMD with age ↑ BMD with activity
Bonjour et al., 1991	207	(9-18 yr.)	DXA	L2 - L4 Femoral Neck Mid Femoral Shaft			Tanner Staging	↑ BMD with maturity Sig. differences between gender
Katzman et al., 1991	45	F (9-21yr.)	SPA DXA	Mid Radius Lumbar Spine Femoral Neck Whole Body	Telephone Questionnaire	Dietary Calcium	Tanner Staging Self Assessment	↑ BMD most rapidly in early teens
Southard et al., 1991	134 84	F (1-19 yr.) M (1-19 yr.)	DXA	Lumbar Spine		Calcium Intake	Tanner Staging	Tanner stages and weight are the best predictors of bone mass and BMD
Glastre et al., 1990	135	(1-15 yr.)	DXA	L2 - L4		Dietary Calcium Vitamin D Serum Bone GLA Protein	Tanner Staging	↑ BMD with puberty

Appendix C

Bone Mineral Density on Children in Sport

Bone response specific to age/maturity

Author (year)	**N(sub)** N(controls)	**Gender (Age)**	**Activity** Type	**Measurements** Bone Scan	Site	**Assessments** Diet	Maturity	**Results**
Cooper et al., 1995	153	F(1968-1969)	Childhood Act.	DXA	Lumbar Spine Femoral Neck	Ca Intake	Chronological Age	Infant growth & childhood activity ↑ BMD in later years
Ruiz et al., 1995	151	F(12.4± 1.8) M(12.3± 1.7)	Hours/wk	DEXA	Lumbar Spine Femoral Neck Trochanter Δ	Ca Intake	Tanner Staging	BMD ↑ with pubertal maturation No sex differences in BMD ↑ hrs. of phys. act - ↑ in BMD Phys. act influence > Ca intake
Young et al., 1995	215 Twin pairs	F(10-26)	Physical Act. (12 months) Questionnaire	DEXA	Total Hip Femoral Neck Ward's Δ	Ca Intake		No effect of Phys. Act., Ca., lifestyle. Limited statistical power in study Sign. relations found between BMD & body composition
Slemenda et al., 1994	90	F&M(6-14)	Questionnaire	SPA DXA	Mid Shaft & Distal Radius L2-L4 Femoral Neck Ward's Δ	Ca Suppl..	Tanner Staging	Phys. Act, Ca, & normal maturation & body size effects BMD Ca intake of 1-1.5 grams/day
Grimston et al., 1993	17	F(13.2± 0.4) F(12.6± 0.4)	Runners (n=3) Gymnasts (n=5) Tumblers (n=7) Dancers (n=2)	DPA	L2 - L4	2-3 day	Tanner Staging	↑ BMD in impact loaded activity groups
McCulloch et al., 1992	68	M(13-17) F(13-17)	Soccer (n=23) Swimmers (n=20)	CT Scanner SPA	Rt. Os Calcis Distal Radius	3 day		↑ os Calcis density in soccer players No difference in BMC in radius

Continued

Bone response specific to age/maturity

Author (year)	N(sub) N(controls)	Gender (Age)	Activity Type	Measurements Bone Scan	Site	Assessments Diet	Maturity	Results
Grimston et al.,1992	74	9-16 yrs	Swimmers	DXA	L2-L4 Femoral Neck	2-3 day kcal/day Dietary Calcium	Tanner Staging	↑ BMD in early Tanner stages 1 & 2 and in late Tanner stages 4 & 5
Slemenda et al., 1991	11	5.3 - 14 yrs	Phys. Activity Questionnaires	SPA DPA	Radius Spine Hips		Tanner Staging	Positive associations made between activity level and BMD

Appendix D

Normative Ranges for Biochemical Markers

Biochemical Indices Value	Age	Gender	Normal Range/Mean
Parathyroid Hormone (PTH)	General	Both	Plasma 1 - 5 pmol/L Serum 10 - 65 pg/ml
Osteocalcin (Os or Gla)	Child		10 - 25 ng/ml
	4-5	Male	1.5 - 28.6 μg/l
		Female	0.9 - 23.5 μg/l
	6-7	Male	8.5 - 28.8 μg/l
		Female	2.4 - 24.6 μg/l
	8-9	Male	13.6 - 29.5 μg/l
		Female	11.2 - 28.1 μg/l
	10-11	Male	12.5 - 33.8 μg/l
		Female	3.6 - 33.8 μg/l
	12-13	Male	3.8 - 29.8 μg/l
		Female	8.2 - 28.4 μg/l
	14-15	Male	7.2 - 42.7 μg/l
		Female	3.4 - 21.6 μg/l
	16-17	Male	3.6 - 27.6 μg/l
		Female	0.6 - 12.4 μg/l
	18-19	Male	1.0 - 23.6 μg/l
		Female	0.6 - 13.4 μg/l
	20-49	Male	6.5 - 13.0 μg/l
		Female	1.0 - 12.5 μg/l
	Adult	Male	4.1 - 10.7 ng/ml
	Adult	Female	1.7 - 10.9 ng/ml
25-Hydroxy vitamin D (25-(OH)-D) * Subject to Diurnal Variation	General	Both	31.6 ± 9.3 ng/ml 25 - 100 pmol/l
Bone Specific Alkaline Phosphatase (BAP)	1-2	Male	100.6 U/l
		Female	90.9 U/l

	3-5	Male	66.3 U/l
		Female	67.4 U/l
	6-7	Male	83.4 U/l
		Female	71.2 U/l
	8-12	Male	75.0 U/l
		Female	83.2 U/l
	13-14	Male	123.1 U/l
	11-12	Female	109.4 U/l
	21-25	Male	13.5 U/l
		Female	11.1 U/l
	29-45	Male	10.3 U/l
		Female	9.8 U/l
Procollagen I (PICP) * Subject to Diurnal Variation	Adult		137.8 ± 43.7
	Children		450.2 ± 241.3
N-Telopeptide (ICTP)	Adult (30-60)		1.8 - 5.0 μ/l
Calcium (Ca):			
Total Ca	Child (9-11)	Both	2.25 - 2.74 mmol/l
	Adult	Both	2.12 - 2.62 mmol/l
Ionized, Free Ca	> 1 mo - Adult		1.0 - 1.35 mmol/l

N.B. Acidosis increases free calcium whereas alkalosis decreases it for a given total Ca.

$$\text{Adjusted Ca (mmol/l)} = \frac{\text{Ca (mmol/l)} - \text{Albumin (g/l)} + 1.0}{40}$$

Taken From: Compilation of a review of the current literature.
Teitz Directory (1990). Clinical Guide to Laboratory Tests (2nd Edition).

Appendix E

Subject Informed Consent Form

Faculty of Physical Education and Recreation
University of Alberta

Skater's Consent Form

Principal Investigator:	Kelly Lockwood	435-3827
Co-investigator:	Dr. P. Gervais	492-1039

The signatures on this form indicate that you, the skater and the parent or guardian will consent for your son/daughter to participate in a study conducted by Kelly Lockwood at the University of Alberta to investigate the impact forces of figure skaters upon landing single, double and triple revolution jumps.

The assessments involved in the project are explained briefly as follows:

Skaters will be asked to perform single, double and/or triple revolution jumps on-ice. Prior to their performance, an insole will be placed in the boot of their respective landing foot. Three repeated trials will be video taped of each jump.

Please consent to reading and understanding the following:

1. You both have received an explanation about the nature of the study and its purpose.
2. All skaters participating are volunteers and can withdraw from the study at any time, without prejudice.
3. The physical stresses are no greater than would normally be experienced by a skater in training or during competition. Video taping and the use of the Emed-System are non invasive and should pose no physical risk to the skater.
4. The skaters names and data remain anonymous and confidential by coding each subject by number. The video records of the participant's performance will be used solely for the research analysis. All video tapes will remain the property of the researcher.
5. The skater will receive a summary of their individual test results, upon request, following the completion of the study.
6. You may ask further questions at any time during the study by contacting:
   Kelly Lockwood
   Dept. of Physical Education & Sport Studies
   University of Alberta
   Lab Tel: 492-7394
   Home Tel: 435-3827

SUBJECT INFORMED CONSENT

CONSENT:

I, (skater's name) ______________________ acknowledge that I have read this form, understand the test procedures to be performed and consent to participant in the above research project.

Signature of Skater ______________________ *Date* ______________________

Signature of Parent (Guardian) ______________________ *Date* ______________________

Skater's Name: ______________________

Address: ______________________

Contact Number: ______________________

Freeskate Test Passed: ______________________

This form should be returned to me as soon as possible.

Your cooperation is sincerely appreciated.

University of Alberta
Faculty of Physical Education and Recreation

Appendix F

A Non-invasive Method for Determining Maturational Status in Children and Adolescents

Maturity Index

Subjects Initials:	Birth date:
Subject Code:	Date:

Instructions:

The following introduction (written or/and verbally) is given to each athlete prior to the assessment.

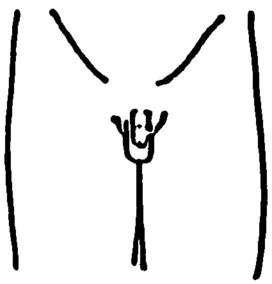
"As you keep growing over the next few years, you will see changes in your body. These changes happen at different ages for different children, and you may already be seeing some changes, other may have already gone through some changes. Sometimes it is important to know how a person is growing without having a doctor examining them. It can be hard for a person to describe herself or himself in words, so doctors have drawings of stages that all children go through. There are 5 drawings of pubic hair growth which are attached for you to look at".

I would like to know how well you can select your stage of growth from the set of drawings. All you need to do is pick the drawing that looks like you do now. Put a check mark above the drawing that is closest to your stage of development then put the sheet in the envelope and seal it so your answer will be kept private.

The drawings on this page show <u>different amounts of male pubic hair</u>.
Please look at each of the drawings and read the sentences under the drawings.
Then check the drawing that is <u>closest</u> to your stage of hair development.

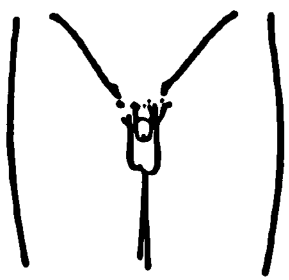
<u>In choosing the appropriate drawing, look only at the pubic hair, and not at the size of the penis or scrotum!</u>

Picture 1 ___



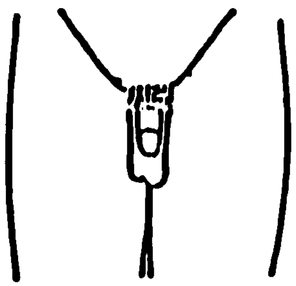
There is no pubic hair at all.

Picture 2 ___



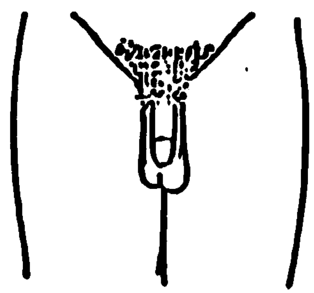
There is a small amount of long, lightly colored hair. This hair may be straight or a little curly

Picture 3 ___



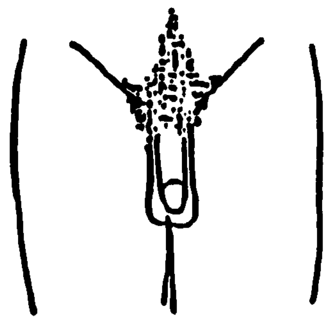
There is hair that is darker, curlier and thinly spread out to cover a somewhat larger area than in stage 2.

Picture 4 ___



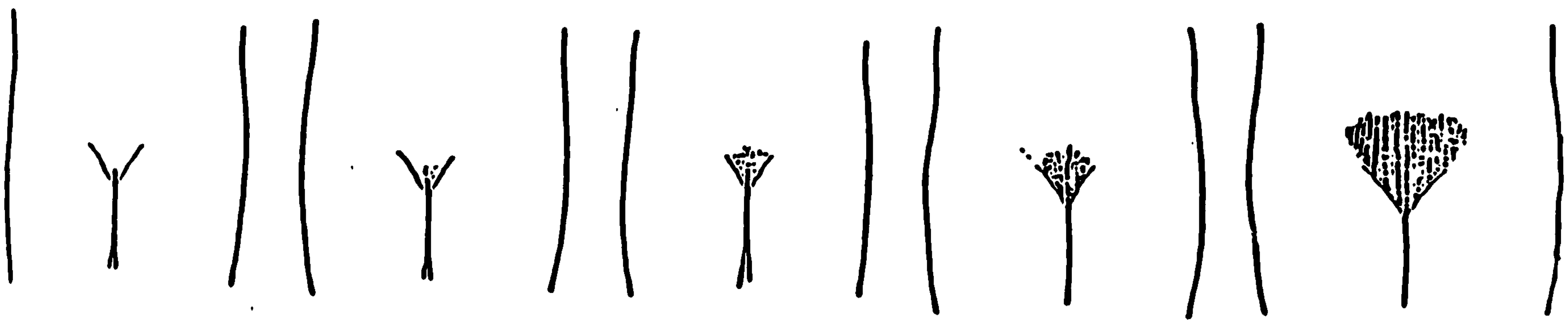
The hair is thicker and more spread out, covering a larger area than in stage 3.

Picture 5 ___



The hair now is widely spread covering a large area, like that of an adult male.

The drawings on this page show different amounts of female pubic hair.
Please look at each of the drawings and read the sentences under the drawings.
Then check the drawing that is **closest** to your stage of hair development.



Picture 1 ___	Picture 2 ___	Picture 3 ___	Picture 4 ___	Picture 5 ___
There is no pubic hair at all.	There is a small amount of long, lightly colored hair. This hair may be straight or a little curly	There is hair that is darker, curlier and thinly spread out to cover a somewhat larger area than in stage 2.	The hair is thicker and more spread out, covering a larger area than in stage 3.	The hair now is widely spread covering a large area, like that of an adult female.

University of Alberta
Faculty of Physical Education and Recreation

Appendix G
Calcium Food Frequency Questionnaire

Calcium Assessment Form

Subjects Initials:	Birth date:
Subject Code:	Date:

Food Type	Standard Serving Size	Usual Serving Size	Frequency					Freq X Serving	Mg Calcium /portion	Mg Calcium /month
			A Day	B Week	C Month	D <Month	E None			
1. Milk	250 ml								314	
2. Buttermilk	250 ml								300	
3. Chocolate Milk	250 ml								300	
4. Ice Cream	125 ml								92	
5. Hard Cheese	45 g								300	
6. Parmesan Cheese	15 ml								69	
7. Cottage Cheese	125 ml								151	
8. Plain Yogurt	125 g								228	
9. Fruit Yogurt	125 g								211	
10. Dried Milk Powder	15 ml								73	
11. Milkshake	250 ml								290	
12. Half & Half (12%)	15 ml								16	
13. Coffee Cream (18%)	15 ml								15	
14. Whipped Cream	15 ml								4	
15. Sour Cream	15 ml								17	
16. Cream Cheese	15 ml								12	
17. Pudding	125 ml								178	
18. Custard	125 ml								157	
19. Rice Pudding	125 ml								137	
20. Pr. Cheese Slices	1 slice								185	
21. Pr. Cheese Spread	15 ml								84	

Food Type	Standard Serving Size	Usual Serving Size	Frequency					Freq X Serving	Mg Calcium /portion	Mg Calcium /month
			A Day	B Week	C Month	D <Month	E None			
22. Clams	7								46	
23. Other Shellfish	90 g								61	
24. Chicken /Beef, etc.	90 g								10	
25. Eggs	1 lg								26	
26. Dried Beans	250 ml								91	
27. Tofu	7x6x2								80	
28. Almonds	125 ml								200	
29. Brazil Nuts	125 ml								130	
30. Other Nuts	125 ml								50	
31. Dark Leafy Greens	125 ml								90	
32. Broccoli	125 ml								94	
33. Mashed Potatoes	250 ml								58	
34. Rhubarb	125 ml								184	
35. Fruit Juice	250 ml								26	
36. Bread	1 slice								23	
37. Pasta/Rice	250 ml								16	
38. Pancakes	each								46	
39. Macaroni & Cheese	250 ml								382	
40. Chili-con-carne	250 ml								86	
41. Cheese Pizza	1/8- 35m								144	
42. Cream Soup (milk)	250 ml								183	
43. Beer	341 ml								17	
44. Wine	100 ml								8	
45. Coffee/Tea	250 ml								7	
46. Chocolate Bars	30 g								35	
47. Other:										
48. Other:										
49. Other:										

Calculations:

Sum of monthly intake ________ / 30 = Daily Intake ________ + 100 non-coded = Adjusted Daily Intake ________

---

* Hard Cheese - Cheddar, Gouda, Brick, Mozzarella
^ Canned fish with bones
# Dried beans - kidney, garbanzo, lima, navy, soy
+ Dark leafy greens - mustard greens, kale (cooked)
" Coffee/Tea - based on the 1987 water analysis for calcium in Edmonton which was 28 ml/l

Calcium contents of foods was taken from the Nutrient Values of Some Common Foods, 1987, which is based on the Canadian Nutrient File, Health Protection Branch, Health & Welfare Canada.

Thank You

University of Alberta
Faculty of Physical Education and Recreation

Appendix H

Activity Inventory Questionnaire

Activity Questionnaire

Subjects Initials:	**Birth date:**
Subject Code:	**Date:**

A/ ACTIVITY

How may hours per day, on average, do you:

Activity	Weekday - Hours	Weekend - Hours
Sleep		
Watch Television		
Study or do Homework		
Just Sit Around		

B/ TRANSPORTATION

Do you walk to school?

Answer	Question	Answer
YES	How long does it take you to walk to school?	
	Do you walk home for lunch?	
	What do you normally do at lunch time besides eat?	
NO	How do you get to school?	Bus
		Parents
		Bike
		Other:

C/ SCHOOL

What do you normally do at recess?

Do you take physical education classes?

Answer	Question	Answer
YES	How many times a week do you have Phys. Ed. classes	
	How long is each class?	
	What do you do during Phys. Ed. Classes?	
NO		

D/ SPORTS

Do you play any other sports beside figure skating?

Answer	Question	Answer
YES	Which sports do you play?	
	How often do you play or practice these sports per week?	
	How long are these practices?	
NO		

E/ WEEKENDS

Do you do activities on the weekends (ie., bike swim, dance, ski, run) other than sport specific training?

Answer	Activities	Approximate Time Spent
YES		
NO		

F/ FIGURE SKATING TRAINING QUESTIONS

Question	Answer
When did you start participating in the sport of figure skating?	
How old were you when you started skating?	
When did you first compete?	

How did you get involved in figure skating?	
Where do you skate?	
How do you get to the arena?	
How many days a week do you skate?	
How many hours a day do you train on- ice?	
How many months a year do you train on-ice?	
How long is your typical free skate session?	
How many sessions do you skate each day?	
How many off-ice workout do you do per week?	
How long does a typical off-ice workout take you?	
How many competitions did you or will you be participating in this 1995/96 season?	

G/ OTHER

Have you been injured in the past one year? YES NO
Please list your injuries:

____

____

Are you currently on any medications? YES NO
Please list them:

____

____

Has your doctor ever diagnosed you with any Bone Disorders or Diseases? YES NO
Please expand:

____

____

Thank You

University of Alberta
Faculty of Physical Education and Recreation

Appendix I

Menstrual History Questionnaire

Menstrual Cycle Questionnaire

Subjects Initials:	Birth date:
Subject Code:	Date:

Please try to answer the questions below as completely and accurately as you can.

1. At what age did you have your first menstrual period? State your age in years and months. *For example, 12 years, 3 months.*

____

2. Is your current cycle regular? *For example every 25-30 days.* Yes No

   If you answered No, when was the last time you menstruated? ______________
   What is the longest time you have gone without a period? ______________

3. How many periods do you have in a year? ______________

4. What is the interval of days between your periods? Indicate the number of days between day 1 (onset of flow) of your period and the day 1 of the subsequent period. ______________

5. On average, how many days does your period last? ______________

6. Has your menstrual cycle been regular from its onset? Yes No

   If you answered No, indicate below which pattern best describes your menstrual cycle occurrence throughout your life since the onset of your first period.

   ________ Regular-becoming irregular
   ________ Irregular-becoming regular
   ________ Never regular

   Does the pattern you selected above repeat itself? *For example, are you regular during some months of the year and irregular during others?* Yes No

7. **Can you identify events that appear to influence your menstrual cycle pattern? List the event and state how it alters the pattern.**

EVENT	CHANGE IN PATTERN	CHANGE IN FLOW
ie., hard training in summer	*irregular*	*lighter*

8. Have you experienced a significant weight loss or gain (12-15 pounds) in the last 12 months?

Yes No

Specify weight lost or gained and over the amount of time weight changed (*ie., Lost 15 pounds in 3 weeks*)

9. Have you ever used oral contraceptive pills?

Yes Are you currently using them?
When did you start using them?
How long (in months or years) did you or have your been taking the pill for?

No

10. Date of day 1 (onset of flow) of your last menstrual period. ____________________

Thank You

Appendix J

Subject Informed Consent Form

Faculty of Physical Education and Recreation
University of Alberta

Skater's Consent Form

Physiological Bone Mineral Density & Biochemical Indices of Bone Trauma in Competitive Figure Skaters

Principal Investigator:	Kelly Lockwood, BPHE, M.Sc.*	492-7394
Co-investigators:	Dr. Gordon Bell, Ph.D.*	492-2018
	Dr. Arthur Quinney, Ph.D.*	492-3364
	Dr. David Cumming, M.D. **	492-6449
	Dr. Patrick Heslip, M.D. ***	428-1121

* Faculty of Physical Education and Recreation
** Faculty of Medicine, Endocrinology
***Associated Radiologists

Subject's Name: ______________________________

You are being asked to volunteer to participate as a research subject in an investigation of Physiological and Biochemical Indices of Bone Trauma in competitive figure skaters. The signatures on this form indicate that you, the subject and the parent/ guardian have read the procedures and will consent for your son/daughter to participate in this study conducted by Kelly Lockwood at the University of Alberta.

Explanation of procedures:

A/ Individual Inventories: A rating of your present maturation status, your nutritional status, your current involvement in activity/training will be assessed in three questionnaires. A meeting will be held with all participants to clarify the procedures.

B/ Physiological Assessment: Anthropometry (height., weight., girth measurements, skinfolds), Flexibility, Anaerobic Power & Capacity (30 second Wingate), Strength Testing (upper and lower extremities), Maximal Oxygen Consumption (VO_2 max).

C/ Biochemical Assessment: A 10 ml blood sample will be taken from the subjects during a resting state. Blood assays will be completed for markers of bone resorption and formation

(Parathyroid hormone, Osteocalcin, 25-OH-Vit D, Bone Specific Alkaline Phosphatase, N-Telopeptide, Procollagen 1, and Calcium).

D/ Bone Mineral Density Assessment: Scans will be conducted on five sites of the body (Spine L2-L4, left and right femoral neck, left and right mid tibia/fibula). Inter and intra subject comparisons will be made to detect differences between the left and right sites of each individual subject and to a control group of comparable biological age and maturity.

Risks:

1. The physiological tests will require some strenuous or maximal effort and with this type of exercise there may be some health risk. The test protocol, including the duration and intensity of effort required during the testing is similar to what competitive figure skaters would regularly encounter during National Team Testing.

2. The biochemical analysis will require 10 ml of blood to be drawn. Some potential adverse effects of venipuncture procedure are localized bruising, soreness, and dizziness. These risks are minimized by using rigorous laboratory techniques and highly qualified personnel. The total volume of blood to be drawn is much less than that given by blood donors in a single donation and no side effects of blood loss are expected.

3. The bone mineral density assessment will be conducted by a Hologic QDR-4500 ™ Dual Energy X- ray Densitometer. This equipment uses very low level of X-rays. Under all operating conditions, the entrance dose to the subject is 2mRem-5mRem, which is about 1/10 of the exposure from a standard chest X-ray.

Benefits:

1. Benefits from participating in this study include a detailed assessment of your personal fitness level as well as biochemical and bone mineral density information.

2. Participation may help provide a better understanding of the effect of repetitive impact training, such as experienced in the sport of figure skating, has upon the bone health of the athlete.

3. The outcome of this study and potential recommendations will be presented to the National Sport Governing Body (Canadian Figure Skating Association).

Protection of Subject's Rights:

1. You the subject and parent/guardian have both received an explanation about the nature of the study and its purpose.

2. All subjects participating are volunteers and can withdraw from the study at any time, without prejudice.

3. The participants names and data remain anonymous and confidential by coding each subject by number.

4. All subjects will receive a summary of their individual test results following the completion of the study.

5. You may ask further questions at any time concerning any aspect of the participation in the study by contacting:

   Kelly Lockwood
   Faculty of Physical Education &Recreation
   University of Alberta
   Laboratory Tel: 492-7394

Appendix K

Bone Mineral Density Assessment Protocols

DEXA Bone Densitometry Protocol

The Hologic QDR-4500 $_{TM}$ X-ray Bone Densitometer uses Quantitative Digital Radiography (QDR $_{TM}$) to rapidly and accurately measure the bone mineral content (BMC) in grams and bone mineral density (BMD) in grams/cm^2 of the designated area of the body.

System Overview: The Hologic QDR-4500 $_{TM}$ X-ray Bone Densitometer uses X-rays of two different energy levels to image and measure the bone mineral content of the designated area of the body. The soft tissues that are contained within the area of interest are subtracted and only the bones are imaged and measured. With the QDR method, the soft tissues do not have a substantial effect on the bone mineral density (gm/cm^2) calculations, therefore the results are accurate for most sizes of patients in the anatomical area desired.

It is not necessary for the operator to select X-ray technique factors; the Hologic QDR-4500 $_{TM}$ X-ray Bone Densitometer's technique factors are fixed for faster, more accurate and consistent results.

Measuring Bone Mineral: To perform the bone mineral density measurements, the operator has the patient lie comfortably on the Hologic QDR-4500 $_{TM}$ X-ray bone Densitometer table and positions the scanning arm over the area of interest. The scanning table is easily moved and the correct starting position for the scan is determined with the help of a laser. The source and detector, which are controlled by the Hologic QDR-4500 $_{TM}$ X-ray Bone Densitometer's computer, are scanned across the area of interest in a serpentine fashion and the information from the detector is stored and calculated by the computer unit. The detector is mechanically connected to the X-ray source so it always remains directly above the arm as the source scans.

The results of the bone mineral content calculation from the displayed image are expressed as bone mineral content (BMC) in grams of calcium hydroxyapatite and bone mineral density (BMD) in grams of calcium hydroxy apatite/cm^2. The Hologic QDR-4500 X-ray Bone Densitometer employs an Automatic Internal Reference System* to correct for changes in tube voltage and current. No daily calibration is necessary by the operator. A quality control phantom should be scanned daily to assure the proper operation of the system.

Dosimetry: The Hologic QDR-4500 $_{TM}$ Bone Densitometer uses an X-ray source rather than a radioactive source to measure bone mineral content (BMC). The Hologic QDR-4500 $_{TM}$ Bone Densitometer uses a very low level of X-rays. Under all operating conditions, the entrance dose to the patient is 2mRem - 5mRem (.02mSV - .05mSV) which is about 1/10 of the exposure from a standard chest X-ray. No additional shielding is necessary for patient, operator or room.