UNIVERSITY OF ALBERTA

A Physical Profile of Male Gymnasts: Knee Muscle Strength, Osteo-Articular Status of the Wrists and Skeletal Maturity.

BY

KEITH WAYNE RUSSELL ©

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **A Physical Profile of Male Gymnasts: Knee Muscle Strength, Osteo-Articular Status of the Wrists and Skeletal Maturity.** Submitted by **Keith Wayne Russell** in partial fulfillment of the requirements for the degree of of Doctor of Philosophy.

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ABSTRACT

The three investigations reported in this thesis were undertaken to study unique aspects of men's gymnastics. One such unique aspect is the very high impact forces that occur when gymnasts land. Eighty-four elite-level gymnasts were found to have hamstrings to quadriceps peak torque ratios (H:Q PTR) that were unusually low (0.5) for elite athletes. Atypically, the gymnasts H:Q PTR did not increase (hamstrings becoming stronger relative to quadriceps) as the velocity of movement increased. These findings have implications for backward landings in gymnastics where the knee is subjected to the combined shear forces of the landing (tibia moving anterior relative to femur) and a similar shear force from the quadriceps contracting eccentrically. Given the large forces that gymnasts must absorb and the incidence of knee injuries, it would seem prudent for coaches and medical practitioners to test and rectify such imbalances as were found in this study.

A second unique aspect of men's gymnastics that was studied was the unusual stresses that gymnasts place on their wrists. The results of the study on the osteo-articular status of 111 wrists indicated that the gymnasts significantly differed (awaiting the final results from one orthopedic surgeon to confirm this) from the age-matched control group. The major differences between the two groups (again waiting confirmation of this) were the number of radial physis involvements in the younger gymnasts and the number of radial and ulnar styloid fractures in the older gymnasts. This latter condition was widespread amongst the gymnasts and had not hitherto been identified in the literature as a

major abnormality. Coaches and medical practitioners should be made aware of the possible pervasiveness of this abnormality.

The third aspect of men's gymnastics that was studied in this series of investigations was whether male gymnasts were late in their skeletal maturation as had been previously found for female gymnasts. Ninety-two male gymnasts had their skeletal ages radiologically assessed and like their female counterparts, were found to be significantly late in their skeletal maturation. There was also a trend for more elite groups to display greater skeletal immaturity. Knowledge of this trend of late maturation has important implications both for coaches of gymnasts and for medical practitioners treating them since late maturing children have increased time during which their physes are open and therefore they are exposed longer to growth related injuries.

TABLE OF CONTENTS

page

CHAPTER I

INTRODUCTION 1

Gymnastics Injuries and Risk Factors

Incidence Rates 3

Onset of Injuries 5

Risk Factors 5

Injury Sites 6

Methodological Differences 7

Gymnastics Injury Summary 8

Physical Attributes of the Male Gymnast 9

Articles Cited 12

CHAPTER II

KNEE MUSCLE STRENGTH IN ELITE CANADIAN MALE GYMNASTS

Introduction 17

Methods 21

Data Analyses 23

Results 24

Discussion 27

Implications 30

Summary 32

Articles Cited 40

CHAPTER III

OSTEO-ARTICULAR STATUS OF THE WRISTS OF ELITE MALE GYMNASTS

Stress-Related Changes in Distal Radial Physes.................... 46

Carpal Stress Fractures 51

Purpose 52

Methods 53

Data Analysis 54

Results 55

Discussion 59

Conclusions 61

Articles Cited 72

CHAPTER IV

SKELETAL MATURITY OF MALE GYMNASTS

Introduction 78

Methods 80

Subjects 80

Procedures 81

Statistical Analysis 81

Results 82

Discussion 83

Articles Cited 93

CHAPTER V

CONCLUSIONS

Knee Muscle Strength in Elite Male Gymnasts 97

Recommendations for Future Research 98

Osteo-Articular Status of the Wrists of Male Gymnasts 99

Recommendations for Future Research 99

Skeletal Age of Male Gymnasts 100

Recommendations for Future Research 102

Summary 103

Articles Cited 104

APPENDIX A KNEE MUSCLE STRENGTH

A.1. Sample letters to parents 106

A.2. Sample data sheets - torque at specific angles 107

A. 3. Sample data sheet - ham:quad peak torque ratio 108

APPENDIX B OSTEO-ARTICULAR STATUS

B.1. Codes for data entry (injury site and injury type) 110

B.2. Sample data tabulation sheet 111

B.3. Sample letter to parents (English and French) 113

B.4. Sample letter to Canadian Gymnastics Federation 114

B.5. Letter to University of Saskatchewan Ethics Committee 118

B.6. Ethics Committee approval 120

APPENDIX C SKELETAL MATURITY

C.1. Sample data sheet with graph of inter-tester scores ... 122

C.2. Scattergram of inter-tester scores used to calculate inter-tester reliability 123

C.3. Sample data collecting sheet used for establishing intra-tester reliability for reader "Russell" 124

C.4. Sample letter to parents (3 sheets in English and 3 in French) 125

C.5. Sample consent form (English and French) 128

LIST OF TABLES

page

Chapter II Knee Muscle Strength in Elite Canadian Male Gymnasts

Table II-1 Physical characteristics of elite male gymnasts........... 33
Table II-2 Mean peak torque (Newton meters)............................ 34
Table II-3 Hamstrings and quadriceps mean torques at 30°, 45°, 60°.. 35
Table II-4 Mean hamstrings quadriceps ratios at 30°, 45°, 60° ... 36

Chapter III Osteo-Articular Status of the Wrists of Elite Male Gymnasts

Table III-1 Abnormalities plotted by site and type - gymnasts ... 63
Table III-2 Abnormalities plotted by site and type - controls...... 64
Table III-3 Abnormalities plotted by site and age group - gymnasts.. 65
Table III-4 Abnormalities plotted by site and age group - controls.. 66
Table III-5 Abnormalities per wrist - gymnasts 67
Table III-6 Abnormalities per wrist - controls................................ 68
Table III-7 Side of injury when 2 hands radiographed 69
Table III-8 Contingency Table for Chi Square Test 70
Table III-9 Contingency Table Left vs Right Wrist....................... 71

Chapter IV Skeletal Maturity of Male Gymnasts

Table IV-1 Studies reporting skeletal ages of gymnasts 85
Table IV-2 Skeletal age of male gymnasts 89
Table IV-3 Contingency table of observed and expected results for club group 90
Table IV-4 Contingency table of observed and expected results for national championship group 91
Table IV-5 Summary of three groups... 92

LIST OF FIGURES

page

Chapter II Knee Muscle Strength in Elite Canadian Male Gymnasts

Figure II-1 Mean angles at which peak torque values were attained 37
Figure II-2 Mean torques at specific angles 38
Figure II-3 Hamstrings quadriceps mean torques ratios at specific angles 39

Chapter IV Skeletal Maturity of Male Gymnasts

Figure IV-1 Months early or late relative to chronological age for club level gymnasts 87
Figure IV-2 Months early or late relative to chronological age for gymnasts at national championship 88

CHAPTER I

INTRODUCTION

The three studies at the core of this thesis are the result of the author's interest in the physical stresses that growing athletes encounter and, in particular, the specific stresses encountered in the sports of gymnastics. The first study dealt with one of the most unique aspects of gymnastics which is the very large forces that are absorbed during landings (27). This study examined the strength of the muscles surrounding the knee. It evolved from a survey of anterior cruciate ligament (ACL) injuries and a subsequent discussion by coaches as to the etiology of this injury.

Another unique aspect of gymnastics is the unusual nature, and amount of stress that is placed on the gymnasts' wrists. A syndrome termed "gymnast's wrist" has been described by several authors (12, 13, 25, 39) but there has not been a sufficiently large study with controls to assess its prevalence, and hence the second study consisted of a radiographic survey of the 111 wrists of male gymnasts in order to examine the consequences of these stresses.

Yet another unique aspect of gymnastics is the young age at which international prominence is attained by female gymnasts and the fact that these elite female gymnasts are not only young but that they are also biologically (skeletally) immature. The third study was, therefore, undertaken to establish whether male gymnasts were, as a population, also late in their skeletal maturity.

Taken as a whole these three studies look at the overall pattern of skeletal development of male gymnasts and at the status of the two joints, the knee and wrist, which absorb the greatest stresses.

Gymnastics encompasses several sports including the three Olympic sports: Men's Artistic Gymnastics, Women's Artistic Gymnastics, and Rhythmic Sportif Gymnastics. In addition to these Olympic sports there are four non-Olympic sports which hold World Championships. These are: Trampoline, Tumbling, Sport Acrobatics and Competitive Aerobics. Of these gymnastics sports, Women's Artistic Gymnastics has attracted the greatest amount of research interest.

This over representation of Women's Gymnastics in the research literature is primarily due to the high media visibility of this discipline, the large numbers of participants, the declining age of the top performers and the intensity of the prepubesent training. Another reason for research interest in this discipline, particularly in North America, is the sudden increase in the number of college and university women's gymnastics teams brought about by compliance with the US Government's Title IX program which legislates that American colleges and universities must balance their complements of male and female teams.

In becoming one of the main beneficiaries of the Title IX program, women's gymnastics has undergone a major change. It has been common for female gymnasts to train and compete intensely before they reach puberty, after which they are often at a physical disadvantage to prepubertal athletes. Instead of retiring after pubescence, as had been a common practice, many American and Canadian females now reduce their training, or even semi-retire, until they are university age and eligible for an American athletic "scholarship," at which time they resume rigorous training. This change to older competitors has led to a dramatic shift in injury patterns and has resulted in increased research interest.

The same has not been true for men's gymnastics which has received considerably less research attention. For example, Meeusen and Borms (28) reviewed 21 studies and only four were directed to Men's Artistic Gymnastics.

Gymnastics Injuries and Risk Factors

Incidence Rates

The incidence rate for injuries in gymnastics, as compared to other sports varies greatly from study to study and between gymnastics populations. Zaricznyj et al. (42) reported an incidence percentage of 3.9% for gymnastics which ranked it seventh of 21 sports studied, while Backx et al. (1) reported that gymnastics injuries accounted for 2.8% of the treatments at their sports medicine clinic which ranked it sixth out of 38 sports.

When males and females are separated, however, the percentages are quite different. In a study by Kvist et al. (21) gymnastics accounted for 7% (75/1124) of all sports related injuries treated over a three year period in a major hospital and female gymnasts contributed almost twice as many injuries as did the males (48 as opposed to 27). Lanese et al. (22) studied eight matched men's and women's intercollegiate teams and found little difference between the injury rates of males and females except in the sport of gymnastics. Women's

Gymnastics experienced 0.82 injuries per 100 person-hours of exposure as compared to 0.21 injuries for the men. With the exception of Lowry and LeVeau (24) all studies have shown a higher incidence of injury for women's gymnastics than for men. Clarke and Buckley (11) reported an injury rate of 2.7 per 1000 hours for females and 1.5 for males, while Whiteside (40) reported 9.7 per 1000 hours for females and 7.7 for males, and Weiker (38) found the incidence to be 4.3 per 1000 hours and 1.3 per 1000 hours in females and males respectively. Another study which looked at nine college women's teams and six college men's teams found the women's teams to have injury incidences almost twice that of men's teams (28.4% as opposed to 16.4%) (11). One study (19) found injury rates in female college gymnastics to be the highest of all sports studied. Although this was a study of only two colleges, it does highlight the need to carefully look at the male / female differences in injury statistics in gymnastics since the high incidence of injury in college women's gymnastics tends to skew the gymnastics injury statistics.

In a review of injuries in women's gymnastics McAuley et al. (26) concluded from several studies that the risk of injury appeared to be proportional to the level of skill of the athletes. Inherent in this conclusion is the knowledge that the most highly skilled athletes train the longest and are therefore exposed to greater risk. In another review Meeusen and Borms (28) inferred that there was a large discrepancy between the rates of injury reported in different types of studies. For example, the two studies which reported the highest rates of injury were prospective studies in which the researchers were in regular contact with the athletes (who kept training diaries in which even minor injuries were recorded)(5, 36). Interestingly, these two investigations had many conflicting results which demonstrates the error of generalizing from case studies. Other studies which reported much lower rates were typically of larger numbers of athletes from mixed elite and non-elite clubs where reporting was not as tightly controlled (33, 38).

Onset of Injuries

The onset of injuries was acute rather than chronic in all investigations except Caine et al. (5). This may, however, reflect the difficulty in collecting slow-onset injury data versus collecting traumatic injury data. It may also be influenced by the propensity of gymnasts to continue training while injured which could easily mask the reporting of slow-onset injuries when researchers question the athletes (34). Although very little has been reported on men's gymnastics, Weiker (38) reported that 50% of the injuries to male gymnasts in that survey were overuse injuries.

Two studies (5, 18) reported relatively high incidences of re-injury which may be more prevalent than has been revealed in the design of other studies. Since these were reported as recurrent injuries it is difficult to determine if they were chronic injuries being exacerbated or whether they were acute injuries recurring.

Risk Factors

The major risk factor for injuries in gymnastics appears to be the skill level of the athlete. That is, the higher levels have far more injuries than the lower levels of gymnastics. Three studies (17, 24, 30) which included club and high school level gymnastics demonstrated very low injury rates for noncompetitive gymnasts. Those studies focusing on competitive clubs and college programs showed much higher rates of injury.

Steele and White (33) found that certain anthropometric characteristics predisposed female gymnasts to injury. When they compared predicted and observed injury scores they found they could identify high and low risk status gymnasts with fair confidence (70% and 79% respectively). The high risk group were taller, heavier, and older. Similar results were reported by Claessens et al. (9) who concluded that female gymnasts who are more mature and relatively tall are at greater risk for developing a positive ulnar variance (ulna longer than the radius). Steele and White also found that hypermobility contributed to injury proneness. The trend for the larger gymnast being more vulnerable to injury was the opposite for young gymnasts (9 years old) reported in Lindner (23) in which the larger, more powerful gymnasts tended to have fewer injuries. The diversity of the studies makes it difficult to generalize other risk factors.

Injury Sites

There appears to be fairly even anatomical distribution of injuries in gymnastics. This does not seem surprising given the design of the Olympic events and the order of events in competition which alternately emphasize lower and upper body. For women's gymnastics there seems to be a predominance for lower extremity injuries while upper extremity injuries are more common in men's gymnastics (28). As expected, injury sites varied depending on the study population.

Methodological Differences

There are many methodological differences between studies on gymnastics injuries that make them difficult to compare to one another. There are various methods employed by researchers to define injury, rate of injury, and injury incidence. For example, Snook (32) defined a major injury as one that was brought to the attention of a physician, while Weiker (37) classified a problem as an injury if it forced the gymnast to either miss practice or modify practice for two days. Caine et al. (5) used the criterion of a gymnast missing any portion of a workout or competition as did Garrick and Requa (17) and Pettrone and Ricciardelli (30).

Variance within these injury studies can also be attributed to different levels of participation (club level, elite level, college level) and various methods of gathering data (retrospective / prospective). Many of the reported studies are in the form of clinical case series. While some of these case series are from large clinics and give a somewhat representative sampling, much of the published data is from small series and even single case reports. Even the larger studies have the shortcoming typical of case series which is that data is representative of the catchment area of a particular hospital or clinic. If there happens to be a very active and elite-oriented club in the area, the incidence of injury for that sport may be higher than if such a club did not exist. Also the statistics may be a reflection of the referral preferences in certain areas and would be distorted if only the most severe cases are reported. That is, incidences of mild or moderate cases will be underrepresented and thus it will appear as if more severe cases exist in the population than actually do.

In the case of differences between male and female injury incidence in gymnastics, some of the data may be skewed since demographic information about the target population is not reported. For example, the fact that there are 100 reported injuries and 70 are female while only 30 are male appears to show that the females have a higher rate of injury. If, however, the rate of participation is much higher in females, (*e.g.* 1000 female gymnasts in the population and only 100 males) then the female incidence of injury is only 7% while the male incidence is 30% and males are at a much higher risk than females. This is the opposite conclusion to what could be inferred by the raw data without demographic information.

Another problem surfaces when authors attempt to identify risk factors from case series data. The case series data may infer that 60% of all reported injuries in gymnastics occur on landings but if the author has not ascertained the percentage of time actually spent doing landings then the exposure time is not known and the inference is flawed. This is similar to taking measurements such as flexibility or strength and inferring that these may be risk factors because the athletes with greatest injury rates had lowest values in these attributes. Without a control group to check this inference it is a flawed deduction. Even with a control group it is, at best, only evidence of an association between the factors. Only when athletes with and without the attributes are followed and their injury incidence established can cause and effect be inferred.

Gymnastics Injury Summary

Much of the data on gymnastics injuries and on risk factors in gymnastics is from studies of female gymnasts. While there are many similarities in the kinds of physical stresses that both male and female gymnasts must adapt to, there are also many differences. There is, for example, much more skill convergence occurring in women's gymnastics. The trend towards more tumbling on balance beam and tumbling-type vaults (round-off onto the beat board) has increased tumbling-type skills and thus narrowed the movement patterns performed by female gymnasts and consequently, increased the number of repetitions of fewer skills. This, in turn, exposes the female gymnast to greater vulnerability to overuse injury. The fact that male gymnasts must train for six different events has the inherent effect of forcing the males to include a wider variety of skills in their training. There are, however, unique stresses that the males must adapt to such as the compression stresses on the wrist from swinging in support on pommel horse and parallel bars and the unique tension stresses associated with swinging on the rings. It is evident that much is still to be learned about the etiology of injuries in men's gymnastics.

The Physical Attributes of the Male Gymnast

There is sparse information on the physical and physiological profiles of male gymnasts. There have only been two thorough anthropometric studies of elite international level male gymnasts. One was conducted at the World Championships in Varna, Bulgaria in 1974 (41) and the second at the World Championships in Rotterdam in 1987 (10). In addition, Carter et al. (8) published somatotype results on a group of gymnasts in 1971 and later assessed 11 male gymnasts at the Montreal Olympics in 1976 (7).

The mean age of international level male gymnasts has dropped slowly from 24 years of age in the Mexico City and Munich Olympics to 21 years (1987 World Championships mean age was 21.9 ± 2.4 years) (10). Despite the age decline, the gymnasts have maintained a mean height of 167 cm. and mean weight of 63.5 kg for several decades, and have physiques high in mesomorphy and low in both ectomorphy and endomorphy. (mean somatotypes of 2-6-2 (7) and 1.5-5.6-2.1 (10)). When compared to Belgian reference data, the male gymnasts at the 1987 World Championships (measured by the same kinanthropometrists) had smaller length dimensions (especially stature which had a mean difference of 9.1 cm.), had shorter leg length relative to stature, were smaller in breadth values (especially femur width), had smaller thigh and calf circumferences but much greater biceps circumference (119% of the reference value), and had much less subcutaneous fat (76% of reference values for 4 skinfolds)

Male gymnasts have been shown to be shorter than non athletes of similar age (4). Calderone et al. (6) found that male gymnasts under 15 years old were smaller in stature and weight than a control group and Österback and Viitasalo (29) found male gymnasts to be shorter than age matched players in basketball, ice hockey and wrestling. Faria and Faria (16) studied the structural characteristics of adolescent (15-17 year olds) American male gymnasts competing for places on the national junior teams. When compared to the top 10 in each of the two junior teams (Class 1 mean age 16.9, Class ll mean age 15.3) they found that the national team members were shorter in stature, stronger in both relative and absolute strength, had greater flexibility, were leaner and had greater muscle mass.

It has been shown that successful female gymnasts are predominantly late maturers (2, 3, 14, 15, 10, 35) but this same phenomenon has not been extensively researched in male gymnasts. Three studies using small samples (20, 29, 31) have shown a tendency for the same pattern to be present in Men's Gymnastics.

In conclusion, these three studies were undertaken to help coaches of elite level male gymnasts achieve that perplexing goal of finding the optimal level of 'stress' for their athletes, without reaching the level of 'distress'. Coaches of pubescent athletes have a particularly difficult task in monitoring the effects of training since these effects can be easily confused with the effects of growth. Coaches of prepubescent athletes also have the complication of dealing with an immature body that cannot be expected to withstand the same kinds of stresses as can a mature body. Paradoxically, there is comparatively little research literature on the prepubescent and pubescent athlete and this is especially true for male gymnasts.

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CHAPTER II

Knee Muscle Strength in Elite Canadian Male Gymnasts[1]

Introduction

The sport of Artistic Gymnastics has undergone many changes which have increased the impact forces that must be absorbed by gymnasts. The most obvious changes have been the increased heights obtainable from spring-loaded vaulting horses and increasingly more elastic floor surfaces; the increased height on dismounts from apparatuses; and the greater landing velocities from the fast tumbling that now precedes dismounts from the balance beam and floor exercise events. Impact velocities of 8.5 m/s generate ground reaction forces in gymnastics which have been measured from 8 to 14 times body weight (16, 21, 23). In the case of the knee joint these forces are absorbed within a joint range of motion (ROM) of 90° resulting in peak angular velocities in excess of 1000°/sec.

Concomitant with these increased heights and velocities has been increased aerial time which, in turn, has tempted gymnasts to increase the number of rotations attempted before landing (and thereby increasing potential for under-rotation at the point of landing). Given the emphasis of a judging

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A version of this chapter has been published. Russell KW, Quinney HA, Hazlett CB, Hillis D: Knee Muscle Strength in Elite Male Gymnasts. J Orthop Sport Phys Ther 22(1):10-17, 1995 system on a perfect landing, all-out effort to 'stick' landings has resulted in further potential for injurious torque at the knee.

In response to concerns about landing injuries in gymnastics, an informal questionnaire was given to coaches at a recent Canadian Level 4 coaching certification course. The questionnaire identified 22 Canadian male and female gymnasts who had sustained anterior cruciate ligament (ACL) injuries (3 of the 10-member Men's National Team had sustained ACL ruptures). Although it is common practice for competitive gymnastics coaches to specifically prepare and condition gymnasts to absorb landing forces, the number of ACL ruptures reported by this group of elite-level coaches would suggest that steps need be taken to either decrease the forces on gymnasts' knees, and/or alter the strength training programs.

When a gymnast lands backward (which is the most common landing), the knees are subjected to two large shear forces. As the feet contact the floor the horizontal linear velocity is checked and the upper leg moves backward relative to the lower leg (femur moving posteriorly relative to tibia). Panzer et al. (23) reported vertical impact forces for a single leg to be 13 x body weight and horizontal forces to be about one half of that. Secondly, a shear force occurs when the quadriceps muscles are eccentrically contracted to absorb the vertical linear momentum. These quadriceps contractions not only cause close compaction of the tibia on the femur, but also pull the tibia forward relative to the femur (lower leg moving anteriorly relative to the upper leg (4, 27, 35, 36). Anterior translation of the tibia resulting from quadriceps contraction occurs from zero degrees to 40-60 degrees of knee flexion. It can be reasoned that the same would be true for eccentric contraction of the quadriceps from zero degrees to 40-60 degrees of flexion (as occurs on gymnastics landings). These shear forces are resisted primarily by the intact ACL (5) which is capable of sustaining tensile forces of 1730 Newtons (400 lb.) (20).

In addition to the passive check-rein of the ACL, there is active restraint provided by the hamstring muscles to limit the anterior tibial translation (27, 35, 36). Mechanisms by which the hamstrings are activated for this stabilizing role include the well known reflexes mediated by muscle stretch receptors, tendon and joint capsule sensory receptors and, more controversially, an ACL-hamstrings stretch reflex (1, 8, 24, 28, 32).

This role of the hamstrings as synergists for the ACL is mediated by the action of the quadriceps muscles. During knee extension (or eccentric flexion), the hamstrings serve as antagonists and provide a posterior pull on the tibia by way of reflexive co-contraction (8). This co-contraction interdependency of the hamstrings and quadriceps recently has been the subject of considerable research related to ACL deficient knees and it has been shown that as force and velocity of quadriceps contraction increases, the co-contraction of the hamstrings also increases which, in turn, increases joint stiffness or stability (8, 32). The interplay of these two muscles is more complicated than outlined here since the hamstrings and one of the quadriceps (rectus femoris) cross both the hip and the knee joint. In the case of the hamstrings this results in the hamstrings shortening as the knee flexes and lengthening as the hip flexes.

Although the role of the hamstrings in preventing anterior excursion or rotatory movement of the tibia is still being researched (24, 32), it is becoming clear that at fast velocities and particularly at knee joint angles of less that 40° of flexion, the hamstrings play a significant role in aiding the ACL in preventing anterior translation and rotation of the tibia.

Assuming that the hamstrings contribute to the stability of the knees of gymnasts during landings, and that the hamstrings and quadriceps are inextricably linked as agonist / antagonist, it follows that there may be a ratio of hamstrings strength (measured as torque) to quadriceps strength that optimizes this ACL synergistic function of the hamstrings. The most common comparative index of hamstrings and quadriceps strength is the ratio of their peak torques when measured on an isokinetic, or more correctly, a 'constant velocity' or 'dynamic concentric' dynamometer. It will be argued in the discussion that angle specific torque ratios would be a better index.

It could be hypothesized that underdeveloped hamstrings are a destabilizing factor relative to ACL ruptures. If the quadriceps are overdeveloped relative to the hamstrings this could, in fact, contribute to ACL ruptures by forcibly pulling the tibia forward during landings. That is, the intrinsic contraction of the quadriceps, when coupled with extrinsic shear forces experienced on backward landings, could be a contributing factor in some ACL ruptures.

A comparable mechanism was postulated in other sports by McConkey (15) and Gersoff and Clancy (7). McConkey observed a pattern of conditions causing ACL injury in expert skiers in which the extrinsic shear force from the "boot-induced" forward rotation of the tibia was coupled with the intrinsic "quadriceps-induced" shear force to cause rupture of the ACL. Gersoff and Clancy suggested that basketball and football players could produce sufficient intrinsic forces with their quadriceps to disrupt the ACL when decelerating and turning.

For the sport of gymnastics there is a paucity of data on ACL injuries and on normative values and ratios of hamstrings and quadriceps torques. Burnie (2) reported that the hamstrings quadriceps peak torque ratio for preadolescent female gymnasts was 0.50 (0.65 at higher velocity) and after a 9 month period of strength training on a dynamic concentric (isokinetic) dynamometer the ratio increased to 0.65 (0.95 at high velocity). Nassar (19) reported ratios (measured in foot pounds) for 51 U.S.A. class I and II female gymnasts (ages were not given) as 0.64 at 60°/sec and 0.69 at 180°/sec.

This present study was undertaken to establish normative values and ratios of hamstrings and quadriceps torque in elite male gymnasts in an attempt to better understand the etiology of ACL injuries in gymnastics.

Methods

A convenience sample of eighty-four male gymnasts were tested for hamstrings and quadriceps strength at the Canadian Gymnastics Championships held in 1991. The gymnasts ranged in age from 12 to 27 years and competed in one of four age groups: <15; <17; <19 and ≥19. Athletes competed in 3 hour blocks over several days and all visited the testing lab between 30 and 45 minutes after completing their first day's competition. The gymnasts were measured for height and weight and their wrists were radiographed to establish their skeletal age and osteo-articular status (for another study). They were tested on a Kin-Com (Chattecx Corp., Chattanooga, TN) dynamic concentric dynamometer which is a hydraulically driven, microcomputer controlled, real time recording instrument that records force, velocity and range of movement. It is programmed to compensate for gravity. Acceptable validity and reliability coefficients have been established for its use. (6, 9, 10, 26, 31, 33, 34).

A practice session consisted of 6 sub maximal contractions on the dynamometer at each of the two test velocities. Only one leg was tested as other studies have established no significant difference in force output between the dominant and non-dominant leg (2, 17, 27). The leg tested was randomly determined in all cases except three who had recent injuries and were tested on their uninjured leg. No eccentric testing was done as the subjects were in the midst of a major competition and both the investigators and several coaches had previously witnessed muscle soreness and injuries with eccentric testing and wished to avoid this likelihood during the competition.

Maximum voluntary dynamic concentric torque generated by the hamstrings and quadriceps was measured with the subjects seated and stabilized with restraining straps around the thigh and chest. As maximum torque usually had been reached in three contractions (13), the subjects performed 6 reciprocal maximum contractions of the hamstrings and the quadriceps through a range of 90°. The leg fully extended was designated 0° and the other limit of movement was 90° of flexion. The first test was performed at an angular velocity of 90°/sec. After a 60 second rest a second test was performed at an angular velocity of 230°/sec. The velocities were chosen to match as closely as possible other studies of elite athletes.(2, 25) In order to eliminate torques which could be influenced by the myotatic reflex, and to minimize machine impact artifacts, data from the last 5 degrees of each end-range were eliminated.

Data Analyses

Peak Torque Values:

Statistical analysis of 2 factors: Muscle and Velocity, each with 2 levels (hamstrings, quadriceps) and (slow and fast) was conducted using ANOVA (3 orthogonal contrasts). In addition, 2 pre-planned non orthogonal contrasts to analyze the simple main effects were included in the analysis. Alpha level was set at .05 for all statistical tests (.05/5 for the 2 non orthogonal contrasts).

Peak Torque Ratios:

Since ratio scores violate the assumption of normality required for ANOVA they were transformed using an arcsine transformation before an ANOVA was used to compare the peak torque ratios at slow velocity versus fast velocity over all 4 age levels.

Joint Angles At Which Peak Torques Occurred:

An ANOVA with 4 pre-planned contrasts was run on each age level. The contrasts were:

1. hamstrings slow vs hamstrings fast.
2. quadriceps slow vs. quadriceps fast.
3. hamstrings slow vs. quadriceps slow.
4. hamstrings fast vs. quadriceps fast.

Peak Torque Values at Specific Angles:

An ANOVA was used to check for differences in the torque values at the three knee joint angles of 30°, 45° and 60°. Separate analyses were done for each age level.

Torque Ratios at Specific Angles:

ANOVA's were carried out for each age group using 2 preplanned (Helmert) contrasts to determine if differences existed between the hamstrings quadriceps ratios at the three different joint angles. Ratio scores were first transformed using an arcsine transformation.

Results

The average height, weight, age (chronological and skeletal) of the gymnasts are presented in Table II-1. As indicated earlier all subjects were regarded as elite Canadian gymnasts.

Peak Torque Values:

Mean peak torque values are reported in Table II-2. The ANOVA main effects showed that the quadriceps generated significantly ($p<.001$) greater peak force than did the hamstrings at all age levels (<15 yr. $df_{21,1}$ $F=263$; <17yr. $df_{17,1}$ $F=446$; <19yr. $df_{10,1}$ $F=139$; ≥19yr. $df_{32,1}$ $F=724$), and the slower limb velocity produced

significantly ($p<.001$) greater peak force than did the faster limb velocity at all age levels (<15 $F=54$; <17 $F=108$; <19 $F=87$; ≥19 $F=366$). The ANOVA interaction effect between the two main effects - speed and muscle - showed that the quadriceps generated significantly ($p<.001$) greater peak torque than did the hamstrings at both the fast and slow velocity at all age levels (<15 $F=43$; <17 $F=36$; <19 $F=32$; ≥19 $F=74$). The ANOVA preplanned contrasts of the simple main effects showed that the slow velocity produced significantly ($p<.001$) greater peak torque than the fast velocity at all age levels in the hamstrings,
(<15 $F=22$; <17 $F=32$; <19 $F=22$; ≥19 $F=67$) and quadriceps (<15 $F=177$; <17 $F=200$; <19 $F=160$; ≥19 $F=414$).

Peak Torque Ratios:

The ratio of peak hamstrings torque divided by peak quadriceps torque was approximately 0.50 for all age groups. This ratio varied only from 0.48 to 0.54 over all groups. No significant differences were found between the hamstrings quadriceps peak torque ratio at slow versus fast limb velocity.

Joint Angles At Which Peak Torques Occurred:

The angles at which peak torques were generated are reported in Figure II-1. There was no significant difference in the angle at which peak torque was generated when the two velocities were compared in each muscle group except for the hamstrings in the <17 age group ($F=12$). When the hamstrings and quadriceps were compared they differed significantly in the mean angles at which peak torque was generated at the slower velocity (compare black bars at each row of Figure II-1; <15 $F=5.4$; <17 $F=13$; <19 $F=14$; ≥19 $F=33$). At the faster velocity (compare open bars at each row of Figure II-1) the two muscle groups were not significantly different except for the ≥ 19 age group (F=10).

Torque Values at Specific Angles:

The mean torque values measured at 30°, 45° and 60° are reported in Figure II-2 and Table II-3. In the quadriceps muscle the torque values differed significantly between the 3 knee angles for all age groups and at both velocities. [Slow (fast) <15 F=34 (F=36); <17 F=30 (F=48); <19 F=65 (F=30); ≥19 F=90 (F=109)]. Such was not the case for the hamstrings. At the slow velocity only two age groups, <19 (F=6.5) and ≥19 (F=26) showed significant (p<.05) differences in the torque values at the 3 knee angles while at the fast velocity only the <17 (F=5.5) showed a significant (p<.05) difference.

Torque Ratios at Specific Angles:

The mean hamstrings quadriceps ratios at specific angles are given in Figure II-3 and Table II-4. In all ages and at both slow and fast velocities there were significant differences (p<.01) between the ratios at 30° compared to 45° and 60° but not between 45° and 60°. Thus hamstring torque decreased relative to quadriceps torque as the joint angle increased.

Slow (fast) <15 F=41(24) <17 F=25(14); <19 F=46(12); ≥19F=210(79).

Discussion

Peak Torque Values

As expected for all ages, the absolute values for peak torques were greater (statistically significant) for quadriceps than for hamstrings and greater at slow (90°/sec) angular velocity than at the faster (230°/sec) velocity (Table II-2).

Peak Torque Ratios:

Absolute peak torque values are usually reported using the ratio of peak hamstrings torque to peak quadriceps torque. Although this index has been extensively studied in the general population and in various sports, the findings are still equivocal. Problems due to the variations in test protocols and the inherent variability of strength testing in general were summarized by Burnie (2) who concluded that there was a degree of specificity toward age, sex, athletic history, level of competitor and test protocol. Although there is general acceptance in the literature that 0.6 represents an average hamstrings quadriceps peak torque ratio value (hamstrings peak torque is 60% of quadriceps peak torque), there is large individual variability, though less in high performance athletes. There appears to be sport specificity and even playing position specificity (11, 25). It does, however, appear consistent that elite athletes (11, 18, 25) have ratios which approach unity at velocities greater than 200°/sec and that the ratio gets larger (hamstrings get stronger relative to quadriceps) as the velocity of movement increases (i.e. as velocity increases the decrement in torque is usually greater in the quadriceps than in the hamstrings). The fact that the hamstrings quadriceps peak torque ratio was close to 0.5 in all age groups and that this ratio did not differ as the velocity increased from 90°/sec to 230°/sec suggests that the hamstrings are not only unusually weak relative to the quadriceps in these gymnasts but that they maintain this relative weakness as velocity increases.

Joint Angles At Which Peak Torques Occurred:

The investigators were interested in establishing the joint angles at which these elite gymnasts generated peak torques. In general, there was a significant difference in the angle of peak torque between the hamstrings (≈40°) and the quadriceps (≈60°) at slow velocity, but no significant difference at the higher velocity (exception being those at age ≥19). The lack of difference at the higher velocity was possibly due to the extreme variability of the angles at which peak torque was generated in the hamstrings (see standard deviations Figure II-1).

Surprisingly there were no significant differences in the angle at which peak torque was generated when the slow and fast velocities were compared. One exception to this was the hamstrings of the <17 age group. Notwithstanding the lack of statistical verification, one must keep in mind the relatively low statistical power available in such analyses, given the numbers studied. Directionally, it is evident (Figure II-1) that the angle at which peak torque was generated in the hamstrings was always larger at the fast velocity and smaller at slow velocity. The reverse was true with quadriceps, though the size of the angle difference was much less obvious.

Torque Values at Specific Angles:

To better understand the force profiles of the knee joint of elite gymnasts the mean torque values were calculated at 3 specific joint angles (Figure II-2).

The hamstrings demonstrated relatively little change between 30° and 60°; while the quadriceps showed significant differences between 30° and 60° at all ages and at both velocities.

Torque Ratios at Specific Angles:

It was noted above that the hamstrings quadriceps peak torque ratio usually reported in the literature compares peak torque values of the two muscle groups without regard to the angle at which the peak values are obtained. In the functioning limb, however, the peak force outputs of the two muscle groups do not occur simultaneously. That is, the peak torques for the two muscle groups occur when the limb is in completely different positions. What is the functional value of an index of these peak torques if the limb never experiences the two peak torques at the same moment? Since the two muscle groups only function simultaneously at a given joint angle, it seems reasonable to compare their torque ratios only at a given angle. If it is possible for an injury to be caused or exacerbated by an imbalance in the force output of these 2 muscles, it would be the imbalance at a given angle that would be germane to the injury and not the imbalance of the peak forces (which occur at different joint angles).

Furthermore, the angular difference in the peak torques of hamstrings and quadriceps is usually exaggerated as limb velocity increases concentrically. With faster limb velocity the angle of peak torque for the quadriceps normally decreases (moves closer to complete extension) and the angle of peak hamstrings torque normally increases (moves closer to complete flexion). Thus at the faster velocities (usual in sports participation) the peak torque ratio without regard to joint angle becomes even more unrealistic as a functional measurement.

Calculation of hamstrings quadriceps torque ratios derived from the same joint angle would seem to be of greater diagnostic value.

Osternig (22) has suggested that 60° is the optimal angle to report torque ratio. In this study torque ratios were reported at 30°, 45° and 60° (Table II-4). These angle-specific ratios varied systematically, reaching their highest value at 30°, their lowest value at 60° and closest to peak torque values at 45°.

In this study the hamstrings torque decreased relative to quadriceps torque as the joint angle increased from 30° to 45° or higher (Figure II-3). Considering the nature of the groups (from prepubertal to mature) it was surprising how similar the hamstrings quadriceps torque ratios were at the 3 joint angles (Figure II-3).

Implications

It has been shown in many studies that the thigh muscles improve knee stability (8, 12, 14, 29, 32). Further, "The antagonist muscle emerges as a principal structure contributing to stiffness and reduced joint laxity"(8). Thus the hamstrings have an important role to play in synergistically assisting the ACL in preventing anterior translation of the tibia. If the quadriceps are much stronger than the hamstrings (as is the case with these gymnasts); if the two muscles are co-contracting (as they are in a gymnastics landing); and if the ACL is already under strain from external shear forces (as they are in a backward landing in gymnastics); then it is plausible (as McConkey (15) has suggested for skiers) that some ACL injuries may be exacerbated by very strong (eccentric) contractions of the quadriceps. This intrinsic shear force of the quadriceps may be even more damaging when insufficiently counterbalanced by much weaker hamstrings.

There are two additional conditions which have implications relative to the results of this study and which could lead to ACL damage during landings in gymnastics. Firstly, landings in gymnastics involve eccentric contractions which usually result in lower hamstrings quadriceps peak torque ratios than concentric contractions (3) thus the force discrepancy between hamstrings and quadriceps would likely be greater (ratio smaller) during an actual landing than was demonstrated using these dynamic concentric tests. Secondly, fatigue results in increased laxity of ligaments and decreased muscle response to ligament mechano-receptors (30). Thus the ability of the knee to withstand the forces of gymnastics landings is further compromised when the tissues are fatigued. This leads to the conclusion that some injuries to the ACL could theoretically be prevented if training was scheduled to eliminate large shear forces about the knee when the legs were fatigued.

The question remaining to be answered is: at velocities as in gymnastics landings which start at 1000°/sec and finish at 0°/sec, can the hamstrings sufficiently assist the ACL in overcoming the large extrinsic shear force that is being magnified by intrinsic shear force from eccentric contraction of the quadriceps? In this study the hamstrings quadriceps ratio is decreasing as the joint angle increases (hamstrings less than 50% of quadriceps at 60°). Conversely, would increasing the force output of the hamstrings (thus increasing the hamstrings quadriceps ratio), particularly at the velocities and at joint angles common during landings, provide a preventative mechanism against this type of ACL injury?

Until further research has been done to investigate these questions it would seem prudent, in light of the apparent increase in ACL injuries and the low hamstrings quadriceps torque ratios of this sample, to: 1) reduce landing forces gymnasts must tolerate by changing the rules to de-emphasize "sticking landings", 2) allow the use of softer landing mats (although this could result in new injuries from the earlier stopping of the feet during longitudinal axis rotations) and 3) alter conditioning programs to reduce the discrepancy between the strength of the hamstrings and quadriceps.

Summary

The results of this study suggest that the hamstrings are not only unusually weak relative to the quadriceps in these elite male gymnasts but that they maintain this relative weakness even as limb velocity increases and across all ages studied. This disparity would probably be greater during the eccentric contractions of gymnastics landings, and thus coaches and therapists should be alerted to the possible implications for knee injury.

Table II-1 Physical characteristics of elite male gymnasts

age level	n	Height (cm) $\bar{X}$	Height (cm) (SD)	Weight (kg) $\bar{X}$	Weight (kg) (SD)	Chronolog. Age $\bar{X}$	Chronolog. Age (SD)	Skeletal Age* $\bar{X}$	Skeletal Age* (SD)
≥19	33	171.27	(5.96)	66.70	(5.25)	20.28	(2.67)	mature	
17, 18	11	166.54	(6.18)	61.72	(6.48)	17.48	(0.66)	17.05	(1.56)
15, 16	18	162.42	(5.38)	55.04	(5.56)	15.40	(0.83)	14.32	(1.34)
<15	22	150.25	(8.91)	41.99	(6.60)	13.41	(0.74)	12.13	(1.59)

* Skeletal age determined by Greulich Pyle method using wrist x-ray.

Table II-2 Mean peak torques (Newton meters).

		Hamstrings				Quadriceps			
		90°/sec (slow)		230°/sec (fast)		90°/sec (slow)		230°/sec (fast)	
n	age	mean	(SD)	mean	(SD)	mean	(SD)	mean	(SD)
33	≥ 19	87.2	(15.7)	66.6	(13.5)	182.3	(27.3)	130.9	(20.4)
11	17, 18	79.5	(15.5)	61.9	(10.9)	162.8	(27.3)	115.1	(18.6)
18	15, 16	64.2	(16.1)	51.1	(14.4)	131.2	(25.8)	98.5	(22.1)
22	< 15	44.4	(12.5)	36.5	(9.6)	91.4	(23.2)	70.9	(15.6)

Table II-3 Hamstring and quadriceps mean torques at 30°, 45° and 60°

		90°/sec (slow)						230°/sec (fast)					
		30°		45°		60°		30°		45°		60°	
age	muscle	$\bar{x}$	(SD)	$\bar{x}$	(SD)	$\bar{x}$	(SD)	$\bar{x}$	(SD)	$\bar{x}$	(SD)	$\bar{x}$	(SD)
≥19	Ham	84	(15)	83	(16)	78	(14)	59	(13)	61	(12)	59	(11)
	Quad	138	(18)	167	(24)	176	(26)	109	(17)	126	(20)	127	(20)
17, 18	Ham	74	(13)	77	(15)	72	(12)	53	(9)	56	(8)	54	(7)
	Quad	121	(21)	149	(27)	158	(27)	99	(20)	112	(19)	112	(18)
15, 16	Ham	60	(16)	60	(16)	59	(14)	42	(14)	45	(13)	44	(12)
	Quad	102	(21)	119	(26)	126	(25)	81	(16)	93	(18)	93	(19)
<15	Ham	41	(13)	40	(12)	38	(11)	30	(8)	31	(9)	30	(8)
	Quad	70	(16)	83	(21)	88	(24)	58	(12)	68	(14)	68	(15)

Table II-4 Mean hamstrings quadriceps ratios at 30°, 45°, 60°

	slow (90°/sec)						fast (230°/sec)					
	30°		45°		60°		30°		45°		60°	
age	$\bar{x}$	(SD)	$\bar{x}$	(SD)	$\bar{x}$	(SD)	$\bar{x}$	(SD)	$\bar{x}$	(SD)	$\bar{x}$	(SD)
≥19	.62	(.10)	.50	(.09)	.45	(.09)	.55	(.10)	.48	(.07)	.46	(.06)
17, 18	.63	(.15)	.52	(.12)	.45	(.09)	.55	(.10)	.50	(.08)	.48	(.08)
15, 16	.59	(.15)	.51	(.11)	.47	(.08)	.51	(.13)	.47	(.09)	.47	(.07)
<15	.60	(.15)	.49	(.10)	.45	(.10)	.53	(.12)	.46	(.09)	.45	(.08)
mean	.61		.50		.46		.54		.48		.47	

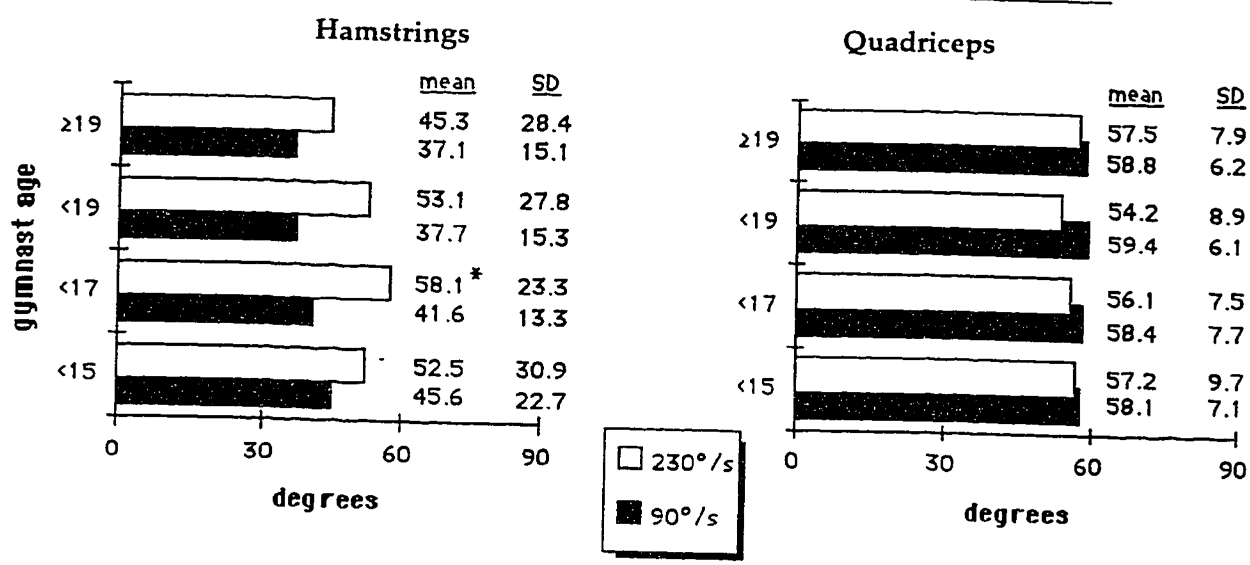

Figure II-1 Mean angles at which peak torque values were attained.
<17 includes only 15 and 16 year olds, <19 includes only 17 and 18 year olds

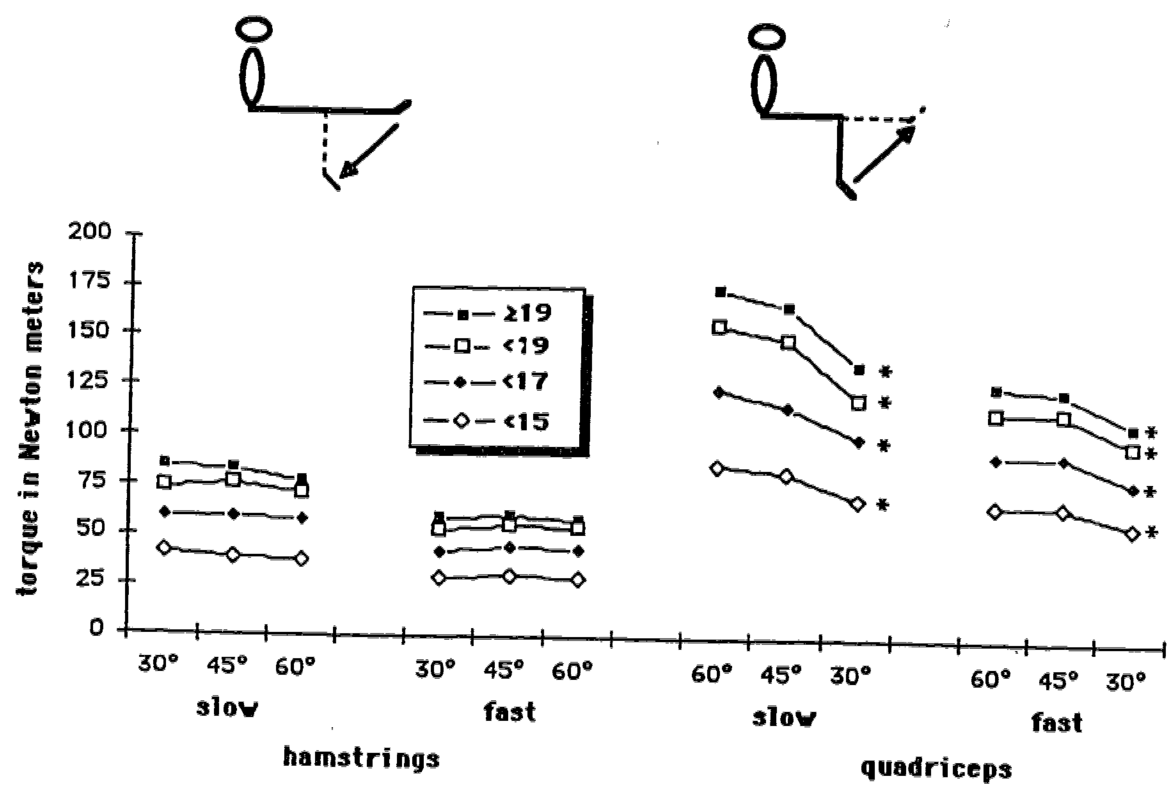

Figure II-2 Mean torques at specific angles. * Significant difference ($p<.01$)
<17 includes only 15 and 16 year olds, <19 includes only 17 and 18 year olds

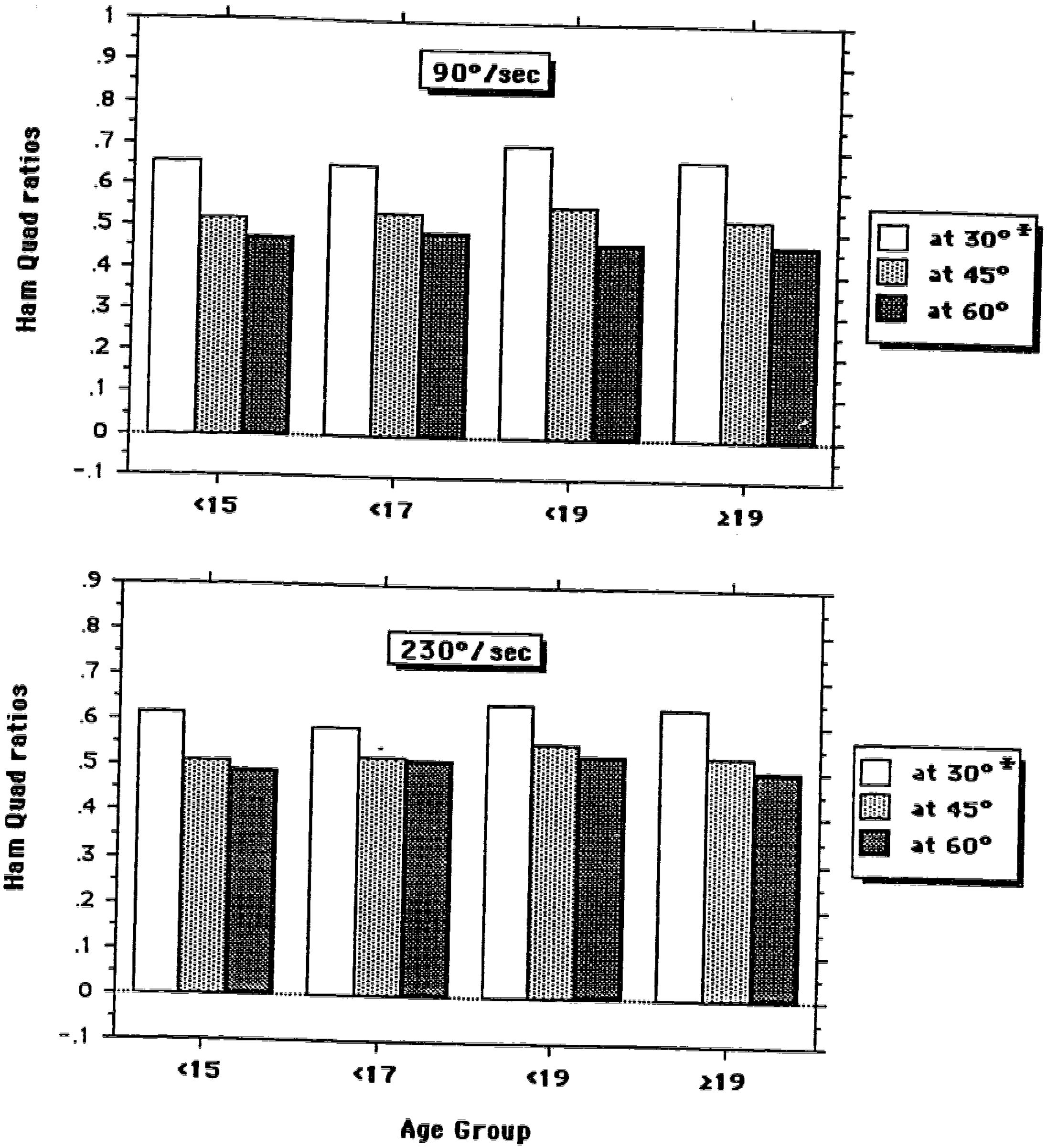

Figure II-3 Hamstrings quadriceps mean torque ratios at specific angles for both slow (90°/sec) and fast (230°/sec) velocities. Within each age group there was a significant drop in hamstrings quadriceps ratios from 30° to 45° to 60°
<17 includes only 15 and 16 year olds, <19 includes only 17 and 18 year olds

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CHAPTER III

Osteo-Articular Status of the Wrists of Elite Male Gymnasts[1]

Men's and Women's Artistic Gymnastics are sports in which athletes generate and attenuate very large forces. Impact forces have been measured as high as 13 times body weight (25) by gymnasts springing from their legs during tumbling take offs and even larger forces - up to 14 times body weight - have been measured during tumbling landings (32). The arms also generate forces measuring 2-3 times body weight on tumbling and vaulting (4, 16, 30) and attenuate traction forces of 7 times body weight on asymmetric bars (15), horizontal bar (10, 18) and as much as 10 times body weight on rings (29). Although the impact forces recorded for pommel horse range only from 1 - 2 times body weight (23), this event is generally considered to be the most punishing on the gymnasts' wrists. The difficulty of this event dictates that athletes must devote longer hours of training to it, and the nature of the event forces the gymnasts to work continuously while supporting on the arms. It is not uncommon for gymnasts to experience 1500 to 2000 impacts per week on this event alone.

The large and repetitive impact forces in gymnastics demand adaptation which is shown in the increased bone density of gymnasts (12, 17, 27, 28, 35)

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There is, however, also the possibility of injurious consequences when placing such large mechanical loads on the musculoskeletal system. The purpose of this study was to examine a cross sectional sample of male gymnasts and controls to determine what effects these mechanical loads have on the wrists of elite male gymnasts.

The literature reveals a sharp increase in recent years in both the number of cases reported and the number of injuries per report (6). While this increase may be due to greater incidence of gymnastics wrist injuries, it may also be due to an increase in diagnostic sophistication through the use of MRI, arthroscopy, etc. Most of the reported cases of trauma involve the distal radial physis or the carpal bones.

Stress-Related Changes in Distal Radial Physes

Single Case and Case Series Studies:

In 1981 Read (33) reported three female gymnasts aged 12, 13 and 16 showing unilateral stress fractures of the distal radial physis. One girl also had an old fractured radial styloid. Read speculated that a particular vault (Tsukahara) was the prime cause of the fractures. He observed that all three girls were injured on the hand that first makes contact with the horse during this twisting vault. The hand (fulcral wrist) is placed in hyperextension and ulnar deviation and then it is torqued hard to generate longitudinal axis rotation.

A Chinese publication in 1983 (19) (translation reported by Caine in 1990) (5) drew attention to 6 cases of lengthened ulnas in gymnasts. In this study 10 male and 18 female gymnasts from Hunan Province in the People's Republic of China were followed for 9 years. These athletes were of national caliber and trained up to 60 hours per week. Once yearly they had radiographs taken of their spinal column, elbows, wrists and ankles. Injury to the distal radial physis was reported in 14 of the 28 gymnasts with 8 of the 10 males and 6 of the 18 females showing signs of injury. There is no indication as to the extent of clinical symptoms. The study reported that the density of the distal end of the physeal line was uneven and "hyperplasia" of the radial styloid was indicated in 4 wrists of 3 gymnasts, one of which also demonstrated a fracture of a radial styloid. There were 2 ulna styloid fractures and in 16 wrists the radioulnar joints were "separated" due to radial growth arrest.

In 1985 Roy et al. (36) reported a case series of 21 gymnasts (19 females, 2 males) from 10 to 17 years of age (mean age was 12) who presented with wrist pain. Seventeen of the 21 had been training 36 hours per week. Radiographic changes were present in 11 of the gymnasts (8 had bilateral involvement, the rest unilateral involvement). Changes included: widening of the radial physis (especially on the radial side and volar aspect); cystic changes (irregularity) on the metaphyseal edge of the physis; and haziness in the radiolucent area of the physis. The authors suggested that these changes represent a stress reaction or a stress fracture process as was described by Read (33). A comparison group of 26 asymptomatic female gymnasts was also part of the study (see cross sectional studies below). The authors refer to "adaptive changes" in the wrists of 8 other gymnasts from the comparison group. These included sclerosis of either side of the physis (mainly on metaphyseal side), calcific lines within the physis, and minimal widening of the radial side of the distal radial epiphysis.

Fliegel (9) reported stress induced widening of the distal radial physis in a 14 year old male and a 14 year old female gymnast.

In 1988 four single case studies of gymnasts with stress related changes to the distal radius were reported. The male gymnast (age 23) in the report by Mandelbaum et al. (21) had positive ulnar variance (ulna longer than the radius) measuring 6 mm. This condition is often associated with a tear in the triangular fibrocartilage complex (TFCC) (31) which was later confirmed with an arthrogram. It was suggested that the lengthened ulna may have resulted from premature closure of the traumatized distal radial physis.

A single case study of a 12 year old gymnast with stress related changes in the distal radial physis was reported by Resnick (34).

In the report by Yong-Hing et al. (41) a 13 year old male gymnast presented with chronic wrist pain which was radiographically confirmed to be associated with distal ulnar physis widening. A year later this gymnast presented again with the same symptoms. The authors hypothesized that the use of dowelled hand grips produced traction stresses which were responsible for these injuries but gave little evidence to refute the more widely held thesis that compression stresses are the cause of gymnast wrist pain.

In the report by Vender and Watson (40) a 17 year old female gymnast with a long history of unilateral wrist pain presented 3 weeks after an injury. Radiographs revealed premature closure of the ulnar side of the distal radial physis resulting in positive ulnar variance and radioulnar joint incongruity. An ulna arthroplasty was performed.

Also in 1988, Carter and Aldridge (7) reported a case series of 21 gymnasts who presented with stress injuries to the distal radial physis. This series included 17 males (mean age of 13.5 years) and 4 females (mean age of 14 years). Radiographs showed widening of the distal radial physes particularly on the volar aspect and haziness of the physes due to irregularity of the border with the metaphyses. The authors also reported the skeletal age of the gymnasts, using Greulich and Pyle Atlas (11) as being on average 16 months delayed in the males and 12 months delayed in the females. They also reported ulnar variance as being normal. An interesting observation from this study was that 11 of the 21 patients had symptoms of other osteochondrites (Scheuermann, Sever, Osgood Schlatter, Sinding-Larsen).

In 1989 Albanese et al. (2) reported three cases of female gymnasts (12, 13 and 14 years old) who presented with unilateral sore wrists which radiographically showed premature fusion of the distal radial physes and concomitant positive ulnar variance on the affected side. Chronic overuse by repetitive sub-fracture loading was suggested as the etiology of these injuries. One patient underwent an ulnar shortening osteotomy.

Ruggles et al. (37) reported a single case in 1991 of a 12 year old female gymnast with bilateral widening of the distal radial physis and that same year D'asnieres de Veigy et al. (8) reported 23 cases of distal radial involvement in young male gymnasts.

Tolat et al. (39) reported 5 cases of positive ulnar variance in female gymnasts aged 13, 16, 18 and 19 which they state were caused by premature closure of the distal radial physes. All cases demonstrated ulno-carpal impingement for which they describe a clinical test. They concurred with the statement of Mandelbaum et al. (20) that wrist arthroscopy allows inspection of the TFCC as well as assessment of the status of the radio-carpal joint

Ahluwalia et al. (1) reported bilateral fatigue fractures in the radial diaphyses of a 24 year old female gymnast who had just increased training from 9 to 18 hours per week.

Cross Sectional Studies

Five cross sectional studies of gymnasts have been reported. Auberge et al. (3) looked at 41 male and 57 female adolescent gymnasts at the European Junior Championships and found that 80% of the males and 85% of the females showed radiographic abnormalities in the form of metaphyseal and epiphyseal lesions.

Szot et al. (38) studied 41 members of the Polish men's national teams (15 to 31 years) and found that radiographic changes were apparent in 58% of the wrists studied but that symptoms were present in only 32%. The authors speculated that this discrepancy may be due to pain-adaptation from lengthy training periods. They stressed that regular radiographic examination was indicated not only for monitoring stress changes but also to detect any congenital anomalies.

Roy et al. (36) used 26 asymptomatic female competitive gymnasts for cross sectional baseline data and reported 3 of these gymnasts had changes related to the distal radial epiphysis (one of whom subsequently became symptomatic) and that 8 others demonstrated changes that were considered as minimal.

In 1989 Mandelbaum et al. (20) reported a cross sectional study of 29 male and 9 female university gymnasts. They used radiographic analysis for ulnar deviation and MRI for soft tissue analysis. This is the only reported study that used non-gymnasts (age matched sample of 20 males and 5 females) as controls. The controls were, however, only used for the analyses of ulnar variance and for width ratios between the ulna and radius . There was no report of radiographic indicators of stress in either the gymnasts or the controls.

Caine et al. (6) screened for stress-related changes in radiographs of the left wrists of 39 female gymnasts (9-17 years) and 21 male gymnasts (9-18 years) and found that 5 of the 60 had discernible change (4 of these were considered to be minimal).

Carpal Stress Fractures

Four case studies of stress fractures of the scaphoid in male gymnasts have been reported. Manzione and Pizzutillo (22) reported a unilateral stress fracture of the scaphoid in a 16 year old male gymnast. Nothing was found on radiographic examination but a polyphosphate bone scan revealed increased uptake in the left scaphoid. In 1989 Hanks et al. (14) reported an additional 3 cases of scaphoid stress fractures in male gymnasts (ages 18 and 19). The authors observed that none of the gymnasts had reported an acute traumatic episode but instead had insidious and intermittent pain for a long time.

Two cases of aseptic necrosis of the capitate bone in a male (age 18) and a female (age 19) college gymnast were reported by Murakami and Nakajima (26). Both cases were reported to be caused by repeated trauma causing a micro-fracture at the isthmus of the capitate bone blocking the blood flow to the proximal portion leading to the necrosis.

Purpose

The purpose of this study was to evaluate by radiographs the osteo-articular status of the wrists of elite male gymnasts ranging from pre puberty to middle age and compare them to age matched controls. There have been many case studies and case series studies of the wrists of gymnasts (1, 2, 7, 9, 19, 21, 33, 34, 36, 39-41), but there has been only one cross sectional study (of college aged subjects) which used a control group (20). There is, therefore, a paucity of information on non college-age male gymnasts and a lack of studies using a control group. This study was also prompted by several trends which are emerging in the sport of Men's Artistic Gymnastics which could result in an increase in the number of overuse injuries to the wrist. Firstly, the age at which elite competitive male gymnasts reach international prominence is decreasing. The mean age of the top 6 teams decreased 3.5 years from the 1968 Mexico Olympics to the 1988 Seoul Olympics (25 years to 21.5 years) (13). Secondly, the number of training hours is steadily increasing. This trend is partly driven by the recent introduction of state sponsored national and regional training centers in many western countries. In these centers, gymnasts train 2 or 3 times per day, for 30 or more hours per week, often under the tutelage of coaches recruited from

China or the former Soviet Union. This increase in training hours per week is also driven by the fact that the break-up of the former Soviet Union has resulted in several more countries (former republics of the U.S.S.R.) vying for the coveted 12-country limit into the Olympic Games.

The third reason for the increased potential for overuse injuries to the wrist of male gymnasts is the many changes to the sport which have resulted in greater impact forces on the athletes. The increased heights obtainable from spring-loaded apparatus such as vaulting horses and floor exercise surfaces result in increased heights and greater landing velocities. Impact velocities of 8.5 m/s generate ground reaction forces in gymnastics which have been measured from 8 to 14 times body weight (6, 24, 32).

The increase in the training exposure time and force absorption is particularly stressful on the wrists of male gymnasts. It is estimated that on pommel horse alone (only one of the six events) an elite male gymnast absorbs 1800 impacts per week on his wrist, each impact varying from 1x body weight to 2x body weight (23). On the other 5 events the number of impacts will be lower but the forces absorbed per impact, especially in the cases of vaulting and tumbling, will certainly be much greater.

Methods

Posterior/Anterior radiographs were taken of 74 gymnasts and 24 ex-gymnasts at the Canadian national championships yielding radiographs of 111 wrists of current gymnasts and 48 wrists of ex-gymnasts for a total of 159 wrists (the youngest athletes had only one hand radiographed). Three orthopedic surgeons (the national team doctor, a hand specialist and a pediatric specialist) and one radiologist independently viewed all the films and tabulated any abnormal occurrences. An abnormality was recorded if it was so identified by at least 2 of the 4 readers. A fifth reader (orthopedic sports medicine specialist) was available if clarification was needed. A control group of non-gymnasts, with birthdays within 6 months of a gymnast, were randomly selected from several medical clinics and subsequently read by the same specialists. The controls' radiographs were all of patients who had presented with hand or wrist injuries but whose radiographs were read as negative with respect to the suspected injuries. It was assumed that the gymnasts, since they were competing at a national championship, also had not suffered recent fractures. Some radiographs were used for controls if the trauma, such as foreign objects from puncture wounds, was deemed unrelated to this study. The 159 radiographs of gymnasts came from 98 individuals (many had both hands radiographed) while the 159 radiographs of the controls came from 121 individuals.

Data Analysis

Descriptive statistics are shown in Tables III-1 to III-6. Two 2 x 2 bivariate frequency tables (contingency tables) were constructed. Table III-8 was used to test the hypothesis that there were no differences in the number of abnormalities between gymnasts and controls. The columns represent the 'gymnasts' and 'controls', the rows represent 'no abnormality' and '≥ one abnormality'. Table III-9 was used to test the hypothesis that there was no difference between the number of abnormalities seen in the right and left hands of the gymnasts. The columns represent the 'left hand and the 'right hand, the rows represent the observed and the expected results. A Chi-Square test of independence using the Yates (continuity) correction was then calculated for each contingency table using 1 degree of freedom (df) and an alpha level of 0.05 on StatViewSE+Graphics computing package for Macintosh computers.

Results

There were 159 wrists radiographed for each of a group of elite male gymnasts and an age-matched group of controls (birthdays within 6 months). In the gymnasts, 62 of the 159 wrists showed one or more abnormalities, while in the control group only 27 of the 159 wrists showed one or more abnormalities (Tables III-1 and III-2). The total number of abnormalities reported for the gymnasts was 81 (in the 62 affected wrists) and for the controls 28 (in the 27 affected wrists). The gymnasts had significantly more osteo-articular abnormalities in their wrists than did the age-matched control group ($X^2 = 18$, 1df, $p<.0001$) (Table III-8).

Percentage of abnormalities in each age group

The percentage of abnormalities in each age group differed markedly between the gymnasts and the controls. In the gymnasts, the percentage of wrists showing 1 abnormality was consistent over all age groups at approximately 30%, but in the controls, this percentage was only 3% in the <15 group, 10% in the 15 and 16 year group, and highest at 31% in the 17 and 18 year group, then declined to approximately 20% in the oldest two groups. The gymnasts and the controls also differed in the fact that multiple abnormalities per wrist occurred in only 1 of the controls while it occurred in 13 gymnasts. Most of these occurrences in the gymnasts were in the 2 oldest age groups (Tables III-5 and III-6)

Location of abnormalities - general

The gymnasts and controls also differed markedly with respect to the anatomical location at which abnormalities occurred. In the gymnasts the most common locations were the ulnar and radial styloid processes (36 of the total 81 abnormalities which included 24 fractures and 9 with hypertrophy). The ulnar styloid was identified twice as often as the radial styloid (25 times versus 11 times including 16 ulnar styloid fractures versus 8 radial styloid fractures). Ulnar styloid involvement occurred in all age groups of gymnasts except the <15 group (Table III-3) but radial styloid involvement only occurred in the older gymnasts (10 occurrences in the 2 older groups, 1 occurrence in the 3 younger age groups). In the controls, the locations of greatest involvement (Table III-2) were the distal radius/ulna (8 abnormalities compared to 5 in the gymnasts) and the metacarpals (7 abnormalities compared to 3 in the gymnasts). The control group had only 7 reports of styloid involvement (25% of all abnormalities) of which 6 were fractures (Table III-4).

In the gymnasts the distal radial physis and the carpal bones were both the second most common sites of involvement. The radial physis was identified 11 times with "wide" or "irregular" abnormalities that all occurred in the youngest two age categories. The carpals were also identified 11 times but all occurred in the oldest two age categories (Table III-1). The abnormalities found in the carpals of the gymnasts were: "cystic" (4), "loose bodies" (3) and "irregular" (4). There were no fractures in the carpals. The involved sites in the carpals were "capitate" (2), "scaphoid" (6) and "lunate" (3).

In the controls the sites of greatest involvement were the "distal radius / ulna" excluding the physes (8 versus 5 in the gymnasts) and the metacarpals (7 versus 3 in the gymnasts).

The number of categories of "sites of abnormalities" was collapsed from the original 11 to the 9 presented in Table III-1. The three general categories "carpals", "metacarpals" and "other" had the following distribution of abnormalities in the gymnasts:

carpals - capitate (2), scaphoid (6), and lunate (3)
metacarpals - fifth (2), third (1)
other - middle phalanx 3rd finger (1), distal radio-ulnar joint (1), ulnar physis (1)

In the controls the distribution was:

carpals - scapholunate (1), lunate (1), lunate-triquetrium (1)
metacarpals - fifth (4), third(1), second (2)
other - proximal phalanx 3rd finger (1)

Table III-7 summarizes the involvement of left and right wrists in the gymnasts in cases where both wrists were radiographed. The left wrist was involved in approximately 60% of the cases and the right wrist 40% but the difference was not significant.

Location of abnormalities - by age group

In the <15 year old group of gymnasts, widening and irregularity of the distal radial physis accounted for 6 of the total 8 abnormalities. In the same age group in the controls, there was only one abnormality reported and it was a sclerotic distal radius.

The 15 and 16 year group of gymnasts had the highest percentage of abnormalities with 14 wrists of 29 (48%) showing one or more abnormalities. These were fairly evenly divided between distal radial physis involvement (9) and styloid involvement (6 ulnar, 1 radial). There were only 3 identified abnormalities in the controls and they were all different.

The 17 and 18 year group was numerically the smallest group and had the second lowest percentage of abnormalities at 31%. The ulnar styloid was involved in 4 of the 5 abnormalities found in this group while the control group also had 5 abnormalities they were all different.

The ≥19 group and the retired group each had abnormalities in approximately 40% of their wrists with the majority of these being radial and ulnar styloid fractures (14 out of 24 abnormalities in the ≥19 group and 11 of 27 abnormalities for the retired athletes). For these two groups the second most common injury site was the carpal bones with 4 and 7 abnormalities respectively. The controls in each of the two older age groups showed abnormalities in half as many wrists (approximately 20% each) which were equally divided between distal radius / ulna abnormalities (5) and styloid abnormalities (5 ulnar, 1 radial).

Discussion

Most reports of gymnastics wrist injuries have been case studies and case series studies of injured athletes and as such cannot be used to generalize whether participation in gymnastics results in increased risk of wrist injury. This was the first study that compared a large number of gymnasts with a contrl group and it found that approximately 80% of the controls and 60% of the gymnasts had no abnormalities in their wrists. The gymnasts, however, had significantly more osteo-articular abnormalities in their wrists than did the age-matched control group ($X^2 = 18$, 1df, $p<.0001$) (Table III-8).

The most unexpected finding was the large number of abnormalities found in the radial and ulnar styloid processes of the gymnasts. The involvement of the radial and ulnar styloid processes to the extent seen in this study has not previously been reported in the literature. While not apparent in the <15 group, by age 15 and 16, there were 4 fractures (3 ulnar, 1 radial) and 3 cases of ulnar styloid hypertrophy from a total of 17 abnormalities (41%). In the oldest 2 groups, the styloids accounted for 50% of the abnormalities (25 of 51). Overall, 20 of the 24 styloid fractures occurred bilaterally in 10 gymnasts. Of these 10 bilateral cases, 6 had bilateral ulnar styloid fractures and 4 had bilateral radial styloid fractures. One athlete, a senior level international competitor, had bilateral radial and ulnar styloid fractures. Fourteen of the 24 styloid fractures were nonunion fractures. Surprisingly, these styloid fractures were mostly asymptomatic. Many gymnasts reported general dull wrist pain but few identified specific pain laterally or medially which would indicate that these styloid fractures are either not a painful condition or that the gymnasts (and retired gymnasts) had become tolerant of the pain.

It has been speculated (41) that the newer type of dowelled hand guard may be responsible for certain wrist injuries in gymnastics. These guards have a transverse dowel attached at the distal end that rests between the bar and the fingers thus increasing the mechanical advantage of the gymnast's grasp. In addition, these hand guards are secured around the wrists by double 2 cm straps or even by single 6 cm wide straps instead of the older hand guards that were secured by a single 2 cm strap. They are secured much tighter around the distal forearm by means of double buckles or Velcro fasteners than were the old style hand guards and this has led to speculation that the tight cinching around the forearm and the traction forces transferred to the forearm during swing may be responsible for avulsion type injuries. This is a particularly compelling theory given the number of styloid fractures and the fact that the newer hand guards are secured very tightly directly over the styloid processes. The results of this study, however, do not completely support this theory since the retired athletes had 11 styloid abnormalities (out of 48 total) and most of these retired athletes would not have used the newer style hand guards. While it is known that the gymnast's wrist is subjected to large compression forces, large traction forces, and also large shear forces, it is not clear which is the cause of the large number of fractures. This question cannot be answered with current data and should be researched further.

Involvement of the distal radius in 15 of the 25 abnormalities found in the two youngest groups was not surprising given that this area has been the most commonly reported injury site in single case and case series studies. Of the 15 abnormalities recorded at the distal radius, 11 involved the distal radial physis while the other 4 abnormalities were identified as "sclerotic (dense) distal radius". These latter four could be interpreted as being an abnormality, that is, etiologically similar to the wide physes or, they could be interpreted as indicating increased bone density and therefore a positive adaptive change. It is difficult to ascertain from radiographs which of these is the case. Nevertheless, the 11 cases of "wide" or "irregular" radial physes as compared to none in the control group is cause for concern.

Conclusions

The many clinical reports of overuse-type injuries in the wrists of gymnasts has led to speculation that intense training in gymnastics may predispose athletes to wrist trauma. Since no studies with a large cross sectional sample and controls had been completed, it was not known how widespread were abnormalities in the gymnastics population. This study of elite male gymnasts has shown that the elite male gymnasts have significantly more osteo-articular abnormalities than controls. It has also shown that the number of abnormalities in the distal radial physes of younger athletes is cause for concern and that coaches and medical practitioners should be closely monitoring the osteo-articular status of the wrists of young male gymnasts and that training of young male gymnasts should be modified to reduce the stresses on the wrists. Furthermore, the high rate of radial and ulnar styloid abnormalities found in this study is cause for concern and further research to determine its etiology should be undertaken. A similar study of female gymnasts should also be undertaken to determine if they also need to be more closely monitored.

Table III-1 Abnormalities plotted by site and type - Gymnasts

	wide physis		sclerotic dist. rad.	fracture				hypertrophy				cystic		loose bodies		irregular*				
	<15	<17	<17	<17	<19	≥19	ret.	<17	<19	≥19	ret.	≥19	ret.	≥19	ret.	<15	<17	≥19	ret.	total
radial physis	2	4	4													4	1			15
distal rad & ulna							2			1									2	5
radial styloid				1		2	5			1								2		11
ulnar styloid				3	1	9	3	3	3		2								1	25
C.M.C. joints																		2	2	4
radio-carp. jt.																		1	3	4
carpals												2	2	1	2			1	3	11
metacarpals					1	1										1				3
other						1										1	1			3
Sub Total	2	4	4	4	2	13	10	3	3	2	2	2	2	1	2	6	2	6	11	
Total	10			29				10				7				25				81

* irregular includes: notching, erosion, stress deformity, spurring, bossing, exostosis
< 17 includes only 15 and 16 year olds, <19 includes only 17 and 18 year olds

Table III-2 Abnormalities plotted by site and type - Controls

	wide physis		sclerotic dist. rad.		fracture				hypertrophy				cystic		loose bodies		irregular*				total
	<15	<17	<17	<19	<15	<17	≥19	ret.	<17	<19	≥19	ret.	<19	ret.	≥19	ret.	<17	<19	≥19	ret.	total
radial physis																		1			1
distal rad & ulna				1			1	1									1			4	8
radial styloid						1	1														2
ulnar styloid							2	2											1		5
C.M.C. joints																					0
radio-carp. jt.																					0
carpals													1						1	1	3
metacarpals					1		1										1	2	1	1	7
other								1													1
Sub Total																					
Total	1				11								1				14				27

* irregular includes: notching, erosion, stress, deformity, spurring, bossing, exostosis
< 17 includes only 15 and 16 year olds, <19 includes only 17 and 18 year olds

Table III-3 Abnormalities plotted by site and by age group - gymnasts

	Competitive Age Groups				
	<15	15, 16	17, 18	≥19	retired
number of wrists	**29**	**29**	**16**	**37**	**48**
radial physis	6	9			
distal radius & ulna				1	4
radial styloid		1		5	5
ulnar styloid		6	4	9	6
Carpo-MC. joints				2	2
radio-carpal joint				1	3
carpal bones				4	7
metacarpals	1		1	1	
other	1	1		1	
total	**8**	**17**	**5**	**24**	**27**

Table III-4 Abnormalities plotted by site and by age group - controls

	Matched Age Groups				
	<15	15, 16	17, 18	≥19	retired
number of wrists	29	29	16	37	48
radial physis			1		
distal radius & ulna		1	1	1	5
radial styloid		1		1	
ulnar styloid				3	2
Carpo-MC. joints					
radio-carpal joint					
carpal bones			1	1	1
metacarpals	1	1	2	2	1
other					1
total	1	3	5	8	10

Table III-5 Abnormalities per wrist - gymnasts

	Age Groups						
	<15	15, 16	17, 18	≥19	retired	total	
gymnasts n=	26	20	9	19	24	98	
wrists n=	29	29	16	37	48	159	
0 abnormalities per wrist	21 72%	15 52%	11 69%	21 57%	29 60%	97 61%	
1 abnormality per wrist	8 28%	11 38%	5 31%	11 30%	14 30%	49 31%	49
2 abnormalities per wrist		3 10%		3 8%	2 4%	8 5%	16
≥3 abnormalities per wrist				2* 5%	3** 6%	5 3%	16
total number of wrists with abnormalities						62	
total number of abnormalities							81

* one gymnast had 3 abnormalities on 1 hand/wrist and 4 on the other
** one coach had 3 abnormalities on each hand/wrist

Table III-6 Abnormalities per wrist - controls

	Age Groups						
	<15	15, 16	17, 18	≥19	retired	total	
controls n=	20	22	10	30	39	**121**	
controls wrists n=	29	29	16	37	48	**159**	
0 abnormalities per wrist	28 97%	26 90%	11 69%	29 78%	38 79%	**132** 83%	
1 abnormality per wrist	1 3.0%	3 10%	5 31%	8 22%	9 19%	**25** 16%	**25**
2 abnormalities per wrist	0	0	0	0	1 2%	**1**	**2**
≥3 abnormalities per wrist	0	0	0	0	0	**0**	
total number of wrists with abnormalities						**26**	
total number of abnormalities							**27**

Table III-7 Side of injury when both hands were radiographed

	Age Groups-Gymnasts					
	<15	15, 16	17, 18	≥19	retired	total
Left	1	6	2	10	17	**36**
Right	1	3	3	8	10	**25**

Table III-8 Contingency Table for Total Wrist Abnormalities

	≥1 abnormality	**0 abnormalites**	row totals
gymnasts	**62**	97	159
controls	**27**	132	159
column totals	89	229	318

Table III-9 Contingency Table Left Versus Right Wrist Involvement

	observed	expected	row totals
left wrist	36	30	66
right wrist	25	30	55
column totals	61	60	121

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CHAPTER IV

Skeletal Maturity of Male Gymnasts[1]

Introduction

Numereous studies (Table IV-1) have shown that competitive female gymnasts are predominately late maturers (skeletal age younger than chronological age by >12 months). Late maturation has distinct biomechanical advantages over early maturation for female gymnasts and may also delay social and emotional pressures associated with maturation. Given that the selection criteria for the sport of gymnastics favours small stature, low adiposity, narrow hips and high strength to weight ratios (1, 11)and that these traits are also associated with late maturation (24), it is plausible that self selection of girls whose physical traits and maturity patterns match these selection criteria could explain in part this skewed distribution.(15) This view is supported by Theintz et al., (20) who demonstrated genetic predisposition to late maturity in gymnasts whose mothers were significantly late in menarche (when compared with mothers from a group of swimmers and a control group of sedentary girls). In one of the few studies conducted on male gymnasts, Keller and Fröhner of the Research Institute of Sport at the Karl Marx University in Leipzig, GDR (13)

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[1]A version of this article will be submitted for publication . Russell KW, Houston CS: Skeletal maturity of male gymnasts. Pediatric Exercise Science.

concluded that late maturing children have a greater opportunity to be selected for gymnastics.

Some studies, however, have indicated that intensive training may be a contributing factor in the late onset of maturity. A study by Ziemilska (23) on Polish gymnasts concluded that decreased dynamics of growth and maturation as well as decreased final outcome of growth may be associated with high training loads both in male and female gymnasts. In the case of female gymnasts, growth may be retarded due to the prolonged inhibition of the hypothalamic-pituitary-gonadal axis combined with (or because of) the metabolic effects of dieting (9, 21). In the 1993 study by Theintz et al. (21) the Swiss female gymnasts demonstrated a homogeneous decrease in predicted height scores over time, corresponding to low growth velocity of the lower limb during mid puberty. In the study by Keller and Fröhner 73% the female East German gymnasts were late maturers (3 years or more) (13). A sample of those athletes suspected of endocrine disturbance were given stimulation tests which, with the exception of 1 athlete, indicated that their endocrine systems functioned normally. It was hypothesized that the latent endocrine regulation disturbances could be partly due to influences originating in the training load, psychological stress and hypocaloric intake.

A study of 22 female Swedish gymnasts by Lindholm et al. (14) concluded that the gymnasts were shorter, lighter, grew more slowly and had late menarche when compared to controls. While such results are well known and their conclusions readily apparent, it is not apparent how Lindholm et al. drew the following two conclusions:

> "Most of the gymnasts had started to train at an early age (seven to eight years), several years before the normal initiation of puberty. Thus, it is probable that their late menarche was a result of early training."
>
> "In relation to the final height of their parents, six of the gymnasts were considerably shorter than their expected height. This suggests an inhibitory effect of the physical activity on growth."

The authors present no compelling evidence to justify these conclusions.

In a study of American triplets, one of which was a gymnast, Tveit-Milligan et al. (22) presents some evidence of possible mild growth retardation and catch-up by the gymnast. The evidence presented, however, does not add strong support to the theory that training was responsible for growth retardation.

The purpose of this study was to determine whether 2 groups of male gymnasts exhibited the same pattern of late skeletal maturity as do female gymnasts.

Methods

Subjects

Two groups of competitive male gymnasts consented to have radiographs taken of their left hand and wrist to determine their skeletal ages. One group of subjects consisted of 36 competitive gymnasts who trained at the University of Saskatchewan (a designated National High Performance Centre for men's gymnastics). Their ages ranged from 8 to 17 and they trained from 3 to 6 times per week. The second group consisted of 56 gymnasts who competed at the national championships. Their ages ranged from 12-18 and all these athletes trained 5 or 6 days per week. An age-group national team was picked from this latter sample and was analyzed separately.

Procedures

Standard Posterior / Anterior radiographs were taken of the left wrists of the gymnasts by 2 technicians at the Royal University Hospital (University of Saskatchewan). The atlas method of Greulich and Pyle (10) was used to determine skeletal age. This method is the standard method used in medicine and was used by the other two studies involving male gymnasts. Two readers (one radiologist who regularly assessed skeletal age and one trained reader) independently rated the radiographs and the ages reported are the means of the two readers. The inter-tester reliability was 0.9.

Statistical Analysis

Descriptive statistics are presented graphically in frequency distributions of the two groups (Figures IV-1 and IV-2) and in tabular form in Table IV-2. These observed frequencies were compared with the expected frequencies derived from the normative data reported in Greulich and Pyle. The standard deviations (SD) for boys aged 9 to 17 in the Greulich and Pyle atlas (calculated and corroborated from nearly 5,000 radiographs), ranged from 9 - 15 months. Using 12 months as the average standard deviation it would be expected that, if the study samples were normally distributed, approximately 16% of the subjects would have skeletal ages <1 SD (late maturers) and 16% would have skeletal ages > 1 SD (early maturers). Contingency tables (Tables IV-3 and IV-4) were tabulated and Chi square goodness-of-fit statistics (X^2) were calculated to test the hypotheses that there was no difference between the observed frequencies and the expected frequencies. A *p* value of less than .05 was used to establish statistical significance in each analysis.

Results

Twenty (56%) were designated late maturers (skeletal age < 12 months from chronological age) and 2 (5%) were designated as early maturers (skeletal age > 12 months from chronological age). Of the 20 late maturers, 6 (17% of total) were late by more than 24 months (Table IV-2). One of these athletes was subsequently diagnosed as having growth hormone deficiency. This group differed significantly from the expected distribution ($X^2 = 14$, 2 df, $p < .001$).

Of the 56 elite gymnasts competing at the National Championships, twenty eight (50%) were late maturers as opposed to only 1 (2%) early maturer. Thirteen (23% of total) were late by more than 24 months but no athletes were early by more than 24 months (Table IV-2). This group also differed significantly from the expected distribution ($X^2 = 50.4$, 2 df, $p<.001$)

From this national championship sample of 56 gymnasts, ten <17 year old were chosen to be on the Age-Group National Team. Five (56%) of these athletes were designated as late maturers with 4 being skeletally late by ≥ 30 months.

Discussion

It has been shown in several studies that elite competitive female gymnasts are predominantly late maturers but prior to this study this trend was not clearly indicated for male gymnasts. Late maturation may have some advantages to the young female gymnast but it also has the disadvantage of exposing the late maturer to a longer time period in which the physes are open and vulnerable to injury. Since males normally mature later than females those male gymnasts who are late maturers could be exposed even longer to this vulnerability. In our study of 2 populations of male gymnasts the subjects were significantly later maturing than expected from normative data in the Greulich and Pyle Atlas.

In a review of the biological maturity status of athletes, Beunen (2) showed that, in most sports, male athletes are characterized by average or early maturity. Late maturity in male gymnasts, as seen in these samples, may simply be a matter of self selection of late maturing athletes out of other sports and into gymnastics. It is also plausible, but impossible to determine from this study, that strenuous training may be a factor in delaying skeletal maturation. There is a trend for the more elite levels to contain greater percentages of late maturers (Table IV-4) which would seem to lend credence to the argument that strenuous training may delay maturation. However, the fact that the younger athletes and those who trained only up to 6 hours per week (younger club-level athletes), also demonstrated this same propensity for late maturation supports the argument that self selection, and not excessive training, is the main reason for this skewed distribution (Table IV-2).

These findings have important implications for medical practitioners treating male gymnasts, and for coaches training gymnasts. Given that there is such a high preponderance of late maturing athletes in gymnastics, and thus an increase in the time during which tissues are immature, there is an increased potential for growth-related trauma. It is difficult to ascertain if male gymnasts are at greater risk than females. The females have 2 fewer events to train for, yet they train similar hours to the males. This means that the females do more repetitions of fewer skills than male gymnasts and thus may be at higher risk for overuse (stress failure) injuries. In addition, there has been a convergence of tumbling-like skills on balance beam and vault which may magnify the trend to increased repetitions of fewer skills. The male gymnasts, however, participate on rings which produces the largest tensile forces in gymnastics (17) and pommel horse which produces the most continuous and numerous compression forces in gymnastics (16).

While the physical adaptations and the robustness of young athletes training for sports like gymnastics are, when not taken to extremes, desirable attributes, the results of this study make it clear that this population has a skewed distribution that includes many very late maturing athletes. It would be prudent therefore for both medical practitioners and coaches to carefully and regularly monitor their growth .

Table IV-1 Studies reporting skeletal ages of gymnasts

authors	year	gender	method	results
Bouchard Malina (3)	1977	females n=7	TWII*	chrono 222.1±22.5 mo skeletal 176.7±8.2 mo
Buckler Brodie (4)	1977	males	pubertal staging	late maturity of schoolboy gymnasts
Jost-Relyveld Sempé (12)	1982	females n=80		very late
Duvallet Léglise (7)	1983	females n=52	TWII	chrono 169.7±9.9 mo skeletal 146.2±14 mo
Caldarone et al. (5)	1986	females n=50	TWII	chrono 14±.9 skeletal 14.2±1.1
Eiben et al. (8)	1986	females	n=18	chrono 13.1±.3 TW 12.9, RUS 12.8
			n=26	chrono 14±.3 TW 13.5, RUS 13.8
			n=11	chrono 15±.3 TW 13.6 RUS 13.9
			n=9	chrono 16±.3 TW 14.5, RUS 15.2

Osterback Viitasalo (18)	1986	males	GP* n=26	chrono 13.9±2.2 skeletal 12.9±2.7 • gymnasts < mean age were later than those > mean age
Keller Frohner(13)	1989	males	GP n=21	chrono 12.3 skeletal 2 years late
Theintz et al (20)	1989	females n=34	GP TWII(RUS)	chrono 12.6±1.1 skeletal 11.0±1.3 skeletal 11.8±1.4 •mothers of gymnasts small & late maturers
Claessens et al. (6)	1991	males females n=113	TWII RUS	did not do skeletal age chrono 15.2±1.3 skeletal 13.8±.8 skeletal 14.3±.9
Rich et al. (19)	1992	males	GP n=8 controls	chrono 131.8±12.8 mo skeletal 114.9±14.9 mo chrono 133.7±6.6 mo skeletal 136.4±10.4 mo • serum testosterone measured; no difference controls & gymnasts

* GP = Greulich Pyle, TW = Tanner Whitehouse, RUS = TW short method.

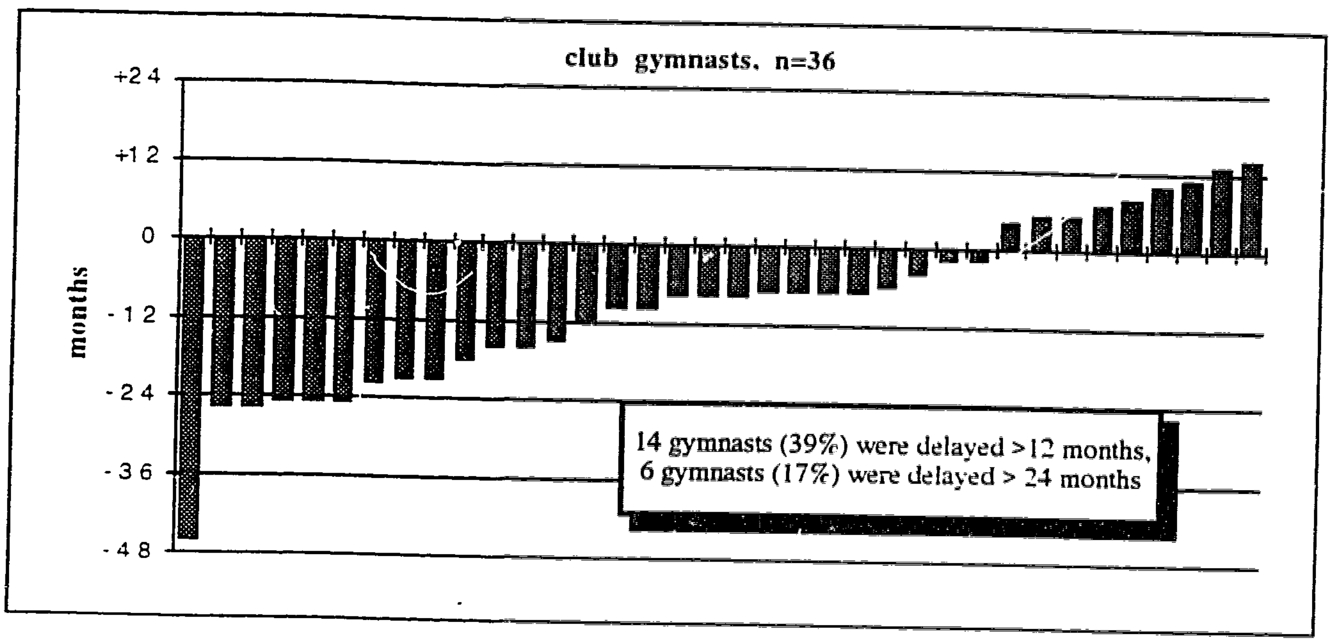

Figure IV-1 Months early or late relative to chronological age for club level gymnasts.

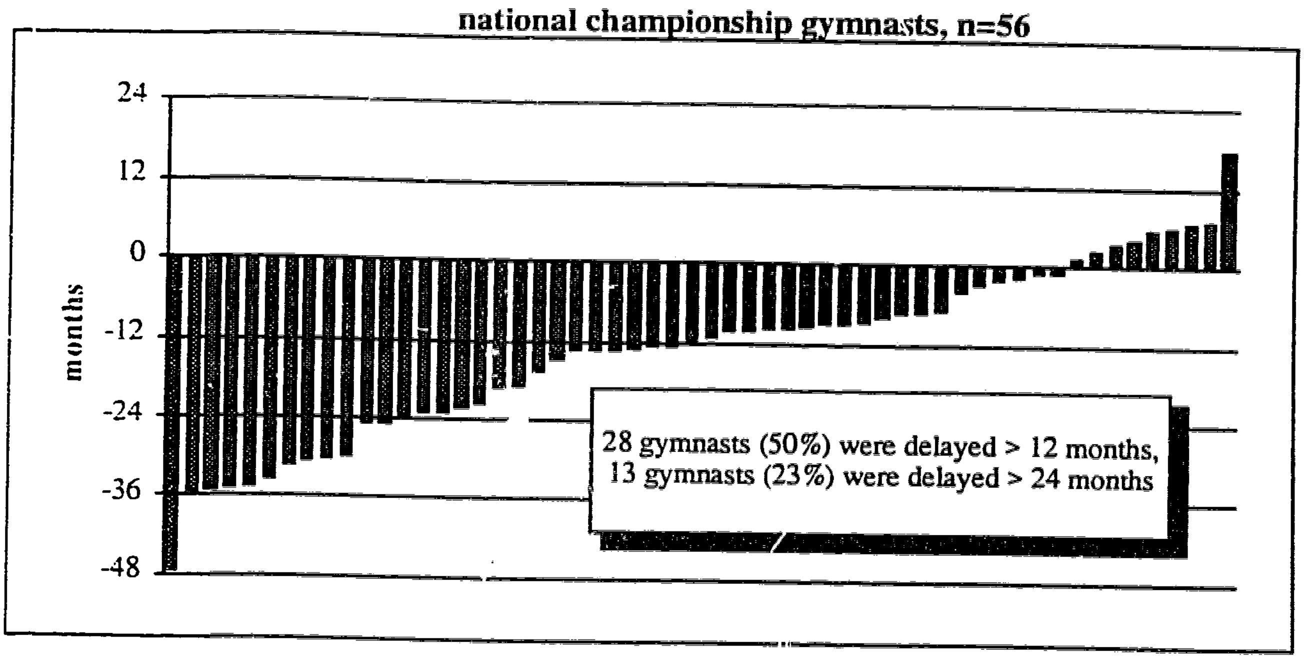

Figure IV-2 Months delayed or advanced from chronological age for gymnasts at National Championship

Table IV-2: Skeletal age of male gymnasts

		National Championships Age Groups					Club Level
		<15	15 , 16	17, 18	Total	<17's on national team	8-17 yr.
	n	24	20	12	56	10	36
mean chronological age (months)		163	185	209	181	177	149
	SD	8	10	8	20	15	34
mean skeletal age (months)		145	171	201	166	160	141
	SD	19	16	18	28	22	34
difference chronological minus skeletal		18	14	8	16	17	8
>12 months early		0	1	0	1 (2%)	0	2
>12 months late		12	12	4	28 (50%)	6	14 (39%)
of above who are > 24 months late		6	5	2	13 (23%)	4	6 (17%)

Table IV-3 Contingency table of observed and expected results - club group.

	Skeletal age relative to chronological age			
	< 1 SD	within ±1 SD	> 1 SD	row totals
observed	14	20	2	36
expected	6	24	6	36
column totals	20	44	8	72

Table IV-4 Contingency table of observed and expected results for national championship group.

Skeletal age relative to chronological age

	< 1 SD	within ± 1SD	> 1 SD	row total
observed	28	27	1	56
expected	9	38	9	56
column total	37	65	10	112

Table IV-5 Summary of the 3 groups

	gymnasts from competitive club n=36	gymnasts at national championships n=56	age group national team n=10
>12 months late	39%	50%	60%
(of the above who are)			
> 24 months late	17%	23%	40%

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CHAPTER V

CONCLUSIONS

Knee Muscle Strength in Elite Male Gymnasts

The three investigations reported in this thesis were undertaken to study unique aspects of men's gymnastics. One such unique aspect is the very high impact forces that occur when gymnasts land. In studying female gymnasts, Panzer(3) measured forces up to 14 times body weight occurring when the gymnasts landed a double backward somersault in tumbling. A meeting of elite-level Canadian coaches identified what seemed to be an increase in the number of anterior cruciate ligament ruptures occurring in the sport (including 3 of the 10-member National Senior Men's team) and this study was then initiated to determine the strength profile of the muscles surrounding the knee. Eighty-four elite-level gymnasts were found to have hamstrings to quadriceps peak torque ratios (H:Q PTR) that were not only unusually low for elite athletes at 0.5, but that were consistently so across all age ranges. The gymnasts also differed from other reported groups in the fact tnat their H:Q PTR did not increase (hamstrings becoming stronger relative to quadriceps) as the velocity of movement increased.

These findings have implications for backward landings in gymnastics (the most common) where the knee is subjected to the combined shear forces of the landing (tibia moving anterior relative to femur) and a similar shear force from the quadriceps eccentrically contracting. If the hamstrings are only 50% as strong as the quadriceps and if they are relatively weaker at greater velocities and at greater angles, then their role in stabilizing the tibia against anterior excursion may be compromised. Given the large forces that gymnasts must absorb, it would seem prudent for coaches and medical practitioners to test for such imbalances and to rectify them.

Recommendations for Future Research

1. Given that the forces actually sustained on landings are absorbed by eccentric contractions future studies should attempt to test the athletes knee strength eccentrically. There are greater chances of muscle injury and greater muscle soreness with this kind of testing so the timing of the testing should not interfere with major competitions.

2. It would be of practical benefit to study the efficacy of different training methods to increase the H:Q PTR at velocities and joint angles which occur during landings.

3. A similar study should be conducted on female gymnasts to determine if they exhibit similar imbalances.

Osteo-Articular Status of the Wrists of Male Gymnasts

A second unique aspect of men's gymnastics is the unusual stresses to which their wrists are subjected. It has been estimated that on pommel horse alone elite-level gymnasts will absorb as many as 1800 impacts per week with each impact varying from 1 to 2 times their body weight (2). There have been many single case and case series studies published about the wrists of gymnasts, however, a large study using controls to determine if gymnasts' wrists differed from normal wrists had yet to be undertaken.

The results of this study indicated that the gymnasts' significantly differed from the control group. The major differences between the two groups were the number of radial physis involvements in the younger gymnasts and the number of radial and ulnar styloid fractures in the older gymnasts. This latter condition was widespread amongst the gymnasts and had not hitherto been identified in the literature as being prevalent. The number of these fractures that were non union (13) and asymptomatic indicates that there may not be long term sequela. Nonetheless, the inevitability of triangular fibrocartilage involvement along with the increased possibility of future complications, indicates that it would be desirable that follow-up studies be undertaken and that researchers, coaches and medical practitioners should be made aware of the possible pervasiveness of this condition.

Recommendations for Future Research

1. A study should be undertaken for female gymnasts to determine if they have similar abnormalities to those identified for males.

2. Future studies should position the subjects for their radiograph with their shoulder abducted 90°, their elbow flexed 90°, and hand pronated so that accurate ulnar variance measurements can be taken in order to compare them with other studies.

3. A follow-up study of these athletes every 5 years would yield valuable information on the progress of abnormalities over time.

Skeletal Age of Male Gymnasts

The third aspect of men's gymnastics that was studied in this series of investigations was whether male gymnasts were late in their skeletal maturation, as had been found to be the case for female gymnasts. Two representative samples of male gymnasts were studied. The first group consisted of 36 club-level competitive gymnasts and the second group of 56 elite-level gymnasts who attended the Canadian National Championships. From the latter group, a sub group of nine athletes chosen to be on the Age Group National Team was also analyzed. In all of these groups the male gymnasts, like their female counterparts, were significantly late in their skeletal maturation. There was a trend for more elite groups to display greater skeletal immaturity. Since athletes in the elite levels of most sports are known to be average or early maturers (1) it is possible that self selection of late maturing athletes out of these sports and into gymnastics may be one reason for this skewed distribution.

Knowledge of this trend of late maturation has important implications both to coaches of gymnasts and to medical practitioners treating them. Late maturing children have a longer period of time during which their physes (epiphyseal and apophyseal) are open and therefore they are exposed for a longer period of time to the growth related anomalies such as Osgood-Schlatter's disease, Scheuermann's disease and to the distal radial physis trauma which has come to be known as "gymnasts wrist". Several case and case series studies have reported gymnasts who presented with damage to the distal radial physis. Some authors have concluded that this has led to premature closure of the distal radial physis. In such a case the ulnar physis is seldom involved, and it continues to grow which results in a longer ulna than radius (positive ulnar variance) and concomitant pain along with possible corrective surgery. The results of surveys of gymnasts have been inconclusive as to the prevalence of ulnar variance.

Another important consideration, relative to the predominance of late maturity in male gymnasts, is the problem of using chronological age as the criterion for advancement to higher levels of competition. It is plausible that a very late maturing athlete would be put at risk if he was forced to move into a more advanced level due to his chronological age. Coaches and medical practitioners must be vigilant of this situation and be prepared to delay advancement if it is deemed to be in the best interest of the athlete. One of the outcomes of this study was that two very late maturing Canadian gymnasts were allowed to compete in the subsequent national championships in an age group below their chronologically determined one. In other words, they were allowed to compete with athletes of the same biological age. In addition, the entire competitive program for men's gymnastics is being redesigned from the basis of a growth and development model that takes into consideration this skewed distribution.

Recommendations for Future Research

1. A maturational index that closelv matches skeletal age should be researched and developed so that ongoing maturational assessments can be made without the necessity of taking hand radiographs.

2. Follow-up studies should be conducted to ascertain if the earliest maturing individuals were more or less successful and if they had more or less injuries than later maturing individuals.

3. A study could be undertaken in which all the radiographs used in this study are re-read using both Tanner Whitehouse II (5) and the Fels Method (4) to ascertain the average differences between these three assessment tools for this representative population of gymnasts. It would be informative to also include a control group of age matched individuals.

Summary

The three studies presented in this thesis were conducted to answer practical questions that existed in Men's Artistic Gymnastics. The result has been the acquisition of new knowledge regarding widespread skeletal immaturity in elite male gymnasts, imbalance and unique pattern of knee muscle strength that is consistent across all ages in elite male gymnasts, and knowledge of abnormalities, particularly widespread ulnar and radial styloid fractures, not previously identified in the wrists of male gymnasts.

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APPENDIX A

Knee Muscle Strength

A.1. Sample letters to parents

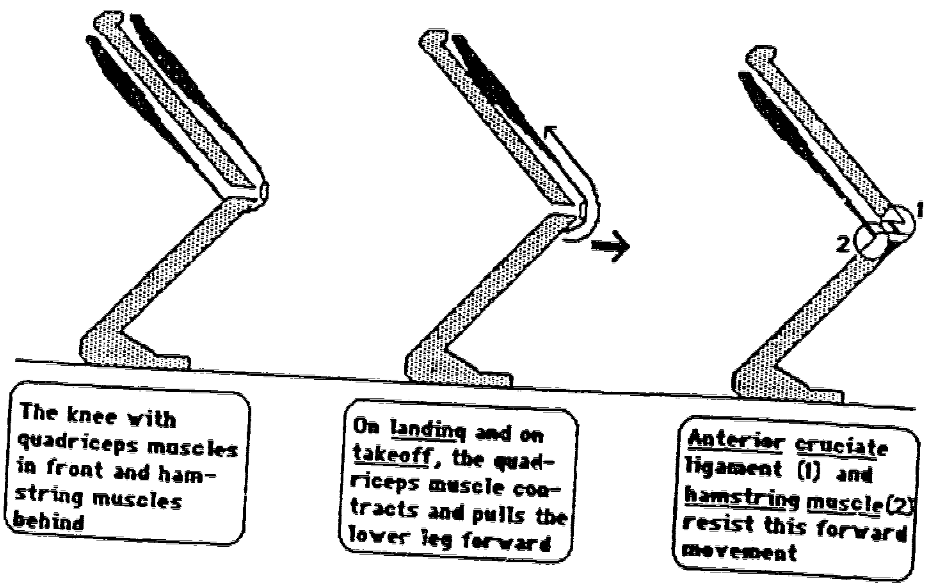
A.2. Sample data sheets - torque at specific angles

A. 3. Sample data sheet - ham:quad peak torque ratio

Test #3. Determining the Ratio of Strength in the Hamstrings and Quadriceps Muscles

By the very nature of gymnastics we tend to develop very strong quadriceps muscles (front of thigh) since they are the prime muscles involved in both take-offs, where they provide the power, and in landings, where they provide the brakes.

It is generally accepted that the strength of the hamstrings muscles (back of thigh) is important in preventing injury to the anterior cruciate ligaments of the knees. Let us illustrate this for you:



As you can see from the illustration, if the quadriceps muscles are disproportionately strong, as we think may be the case in gymnasts, then the hamstrings may not be strong enough to withstand the stress (force of landings <u>plus</u> the force of quadriceps muscles contracting to slow down the landing), thus resulting in damage to the cruciate ligament. There have been a few cases of this injury including 3 of the current senior national team members and 2 from our gym in Saskatoon. We will use a KinCom isokinetic dynamometer to measure the leg strength to determine if it is common for national level gymnasts in Canada to have overly strong quadriceps relative to their hamstrings, and if so, alert coaches and athletes of this fact.

				<15 year olds							
	quad 90			quad 230			ham 90			ham 230	
30	45	60	30	45	60	30	45	60	30	45	60
65.2	73	82.4	48.4	57	58.6	35	36.6	35	27.6	28.4	28.6
69.9	82.2	83.1	53.6	65.1	65.5	22.2	22	23.5	23.1	24.2	24.4
46	47.6	45.6	37.4	41.4	39.4	27.8	25.6	23	22.6	22.2	20.8
89.6	111.3	122.3	71.6	84.2	84	39.4	44.5	47.7	28	27.1	27.3
52.6	66.2	66	43.8	51.8	49.6	32.4	30.2	27	23	21	18.2
77.8	111.1	124	64	84.7	92.6	64.9	65.1	58	42.9	44.8	44
101.6	111.7	113.1	82.3	92.9	87.6	50.4	54.6	51.5	30.5	31.9	35
86.4	99.2	103.2	73	77.2	77	42.2	39.2	35.6	32.2	31.4	27.2
62.6	81.7	94.2	48.1	62.2	59.4	40.4	37.4	35.4	25.7	27.8	27.4
82.7	94.1	107.1	64.4	79	82.9	64.4	65.9	62.4	44.4	45.4	47.6
78.7	94.5	95.2	65.5	72.9	73.2	45.3	46	43	28.3	28.8	28.3
81.9	104.3	114.6	71.1	85.6	90.5	61.5	60.6	56	49.7	49.7	47.6
60	62.5	64.7	46.6	53.6	57.1	38.6	35.8	36.2	27.4	28.2	26.1
50.5	59	61	44.8	50.5	51.4	27.6	29.2	31.3	21.2	23.7	24.9
59.8	75.9	83.1	52.8	64.1	61.6	48.5	44.7	40.2	29.3	31.5	31.6
64.1	77.4	79.7	68.2	72.5	67.8	37.6	38.2	40.9	28.8	33.3	32.9
87.3	95.3	93.6	74.6	78.5	76	31.2	34.7	35.1	28.2	30.4	28.8
61.6	81.2	90.6	49.8	61.8	66.8	40.8	39.8	37.6	28	27.4	26.8
42	45.5	51.2	46.8	52.1	55	19.3	20.9	19.8	22.8	22	22.6
78	96.4	102.7	64.2	78.2	83.9	33.5	37.9	41	27.8	27.3	29.1
78.1	65.1	65.5	60.9	77	84.9	64.6	24.4	24.4	51	51.9	47.5
61.4	65.1	55.5	49.5	50.7	49.5	40.9	43	43.4	22	25.3	24.5
89.2	115.8	125.2	65.4	73	58.4	63.6	61.2	55	38	38.6	32.6

Under 15 scores minus the 2 lowest (immature)

age level	nat'l team	quad 90	quad 230	ham 90	ham 230	H:Q 90	H:Q 230
under 15	age group	87.6	60	36.8	28.6	0.42	0.43
under 15		86	66	26.6	28.1	0.31	0.47
under 15		124.3	86.9	49.9	40.9	0.40	0.58
under 15		70.4	52.2	33	23.4	0.47	0.54
under 15		124.7	99.2	66.6	57.4	0.53	0.49
under 15		113.9	92.9	57.4	50.4	0.50	0.49
under 15	age group	104.2	81.4	42.6	39.8	0.41	0.40
under 15		101.6	61.8	42.4	30.2	0.42	0.56
under 15		97.6	74.1	47.5	29.7	0.49	0.56
under 15		118	91.3	63.4	51.4	0.54	0.45
under 15		65.5	58.8	38.8	31.5	0.59	0.43
under 15		61.6	52.2	32.1	31	0.52	0.59
under 15		84	65.5	49.7	32.7	0.59	0.41
under 15		80.1	74.1	41.3	41.7	0.52	0.62
under 15		95.5	78.7	35.8	35.4	0.37	0.70
under 15	age group	90.6	67.2	42.2	29	0.47	0.55
under 15		104.7	87.6	42.9	36.1	0.41	0.59
under 15		104.5	85.8	65.1	53.4	0.62	0.62
under 15		71.1	52	43.8	36.2	0.62	0.50
under 15		126.4	73	63.6	40.4	0.50	0.48
	mean	95.62	73.04	46.08	37.37	0.49	0.52
	St Dev	19.98	14.57	11.74	9.50	0.09	0.08
	min	61.60	52.00	26.60	23.40	0.31	0.40
	max	126.40	99.20	66.60	57.40	0.62	0.70
	count	20					
under 15	age group	48	42.6	27.8	22.6	0.58	0.45
under 15		51.4	56.5	26.6	33.6	0.52	0.53

APPENDIX B

Osteo-Articular Status

B.1. Codes for data entry (injury site and injury type)

B.2. Sample data tabulation sheet

B.3. Sample letter to parents

B.4. Sample letter to Canadian Gymnastics Federation

B.5. Letter to University of Saskatchewan Ethics Committee

B.6. Ethics Committee approval

Orthopedic and Radiologist's Comments

Injury Site Code

1. radial physis
4. distal radius & ulna
5. radial styloid
6. ulnar styloid
7. Carpo-MC. joints
8. radio-carpal joint
10. carpal bones (bone abbrev.)
11. metacarpal bones
12. other

Injury Code

W wide joint/physis
S sclerotic change
F fracture (NU=nonunion)
H hypertrophic / prominent
C cystic change
L loose bodies
I irregularity

National Championships Wrist X-ray Study (15 &16 yr.)

name	Nat'l team	1st Orthopedic Surg. Comments	2nd Orthopodic Surgeon's Comments
		x	some sclerosis distal radius (with cyst forming)
		x	x
		x	x
		R. radial physis wide laterally	R. distal radial physis wide
			base R. 3rd MC old #
			bilateral lunate bone islands
		x	x
		x	x
		distal radial physis wide??	wide irregular distal radial physis especially on diaphyseal side
	AgeGr	radial physis slightly wide	
			sclerotic distal radius adjacent to physes
			sclerotic distal ulna adjacent to physes
	jr.	ulna styloid # (salter 3) healed	L. ulna styloid basal # (malunion),
			R. ulnar coll. lig. avulsion #
	AgeGr	x	x
		x	sclerotic distal radius,
			prominent ulnar styloid
		R.distal radius (lateral) widening	distal radius (prox. aspect of physis) erosion?
		radius physis slightly wide	radial physis (proximal aspect) cystic changes
		x	x
		x	x
	jr.	recent radial physeal #? (dense prox. radial physeal line)	L. increased density (or sclerosis) distal radius
		L.ulnar styloid tip avulsion (or accessory bone),	L.ulnar styloid tip avulsion (or accessory bone),
		R. ulnar styloid basal #	R. ulnar styloid basal #
	AgeGr	old # L. radial styloid	old avulsion # radial styloid
			prominent ulnar styloids
			" " "
		x	distal ulnar styloid prominent
		x	x
		x	irregularity of distal ulnar physis

National Championships Wrist X-ray Study (15 &16 yr.)						
3rd Orthopedic Surgeon's Comments	Radiologist's Comments	hand	# of x-rays	Site Code	Injury Code	name
x	radial physis too wide margins sclerotic		1	1	S	
x			1			
x	R. radial physis too wide		2			
R. radial physis widening,	R. radial physis too wide	R	2	1	W	
	bilateral lunate boney islands (no significance)					
distal radius (both sides) several "growth arrest lines"						
x	short ulnar styloids		1			
x			1			
widened radial physis	L. radial physis damaged		1	1	W	
	radial physis wide		1	1	W	
	radial physis sclerotic			1	S	
oblique orientation to ulna??						
L ulna styloid # (recent)	L. ulnar styloid #	L	2	6	F	
x			2			
x	R radial physis margins sclerotic		1	1	S	
radius physis widening	L. radial physis wide	L?	2	1	W	
lucency prox. to radial physis			1	1	I	
x			2			
x	L. & R. radial physis wide		2			
increased density prox. radial physis (esp. L.)	L. & R. radial physes sclerotic and wide	L	2	1	S	
L. ulnar styloid #,	L. ulnar styloid ossicle	L		6	F	
		R		6	F	
ossicles or old # L. radial styloid	radial styloid non union	L	2	5	F(NU)	
very broad ulnar styloids	wide ulnar styloids	L		6	H	
" " " "	" " "	R		6	H	
ulnar styloid elongated	long ulnar styloid		1	6	H	
x	periosteal new bone along radius		1			
x	"bridges" across ulnar physis ?stress?		1	12	I	

Test #2. Examine Gymnasts With Potential Growth Plate Injury

Recent research in England and China has indicated that some of the wrist pain that is quite common in gymnasts is due to injury to the distal radial epiphysis which is the growth plate close to the wrist, on the radius bone (thumb side of the forearm). While not alarming, these results suggest that we should monitor our own gymnasts more carefully.

Dr. Doug Ritter, who is the Men's National Team Doctor, will work with us to identify those athletes who have positive signs of potential growth plate injury. These athletes will be offered the opportunity of getting additional x-ray views of the wrists taken and these, in turn, will be read not only by Dr. Ritter, but also by a pediatric orthopedic surgeon. Dr. A. Dzus, and a radiologist, Dr. C.S. Houston, both from Saskatoon.

Each athlete's results will be confidential and will be communicated to the parents and hopefully through them to the coach and family or club doctor. A general summary of results will be sent to all participants.

Let us emphasize that there is not much evidence that growth plate injuries are common in gymnastics. But since wrist pain is widespread amongst gymnasts it is prudent for us to conduct research into the source of the pain.

We are particularly sensitive of this issue in Saskatoon because several years ago we had a young gymnast (who ranked 3rd in the country) sustain a wrist injury that was identified too late as a growth plate injury and consequently was not monitored closely enough. He was forced to retire from the sport because of the injury.

To: Hardy Fink, Rob Paradis, Doug Ritter,
From Keith Russell
Re. Testing Athletes at National Championships, Saskatoon.

Part I X-rays for Maturation Status

I have spoken to all of you about the possibility of taking wrist x-rays of all of the national team members while they are in Saskatoon. Let me review some of the advantages of doing this.

1. Radiographs (X-rays) are the most accurate way to assess skeletal (biological) age.

2. Athletes are most vulnerable to several kinds of bone / cartilage injuries (osteochondroses) while they are in their adolescent growth spurt. (see Caine and Lindner article in March 1990 CAHPER Journal outlining 10 factors that uniquely predispose prepubescent and pubescent athletes to injury).

3. Knowing the skeletal age lets us determine if the athlete is **late** or **early** maturing.

4. Knowing if an athlete is **early** maturing tells us that:

   - he will experience the typical adolescent decrease in flexibility sooner than other boys his age and thus be more vulnerable to avulsion (traction) injuries because of the tractioning of muscles and tendons and ligaments due to rapid bone growth

   - early maturers tend to be physically advanced for their age but can face psychological problems when other athletes mature and catch up.

   - early maturers can be introduced to more demanding conditioning programs earlier than other boys their same age. (that is, they are physically mature sooner and not vulnerable to growth related injuries for as long a period of time as late maturers are).

5. Knowing if an athlete is **late** maturing tells us that:

   - he will be vulnerable to growth related injuries for a longer period of time.(sometimes three to four years longer than early maturers!)

   - he will be disadvantaged in strength / power relative to boys his age. (often with concomitant psychological problems)

   - he will be particularly vulnerable tc overuse-type injuries

   - he should not be given as severe a conditioning programme as boys his own age and especially not as severe as early maturers his own age.

6. Knowing what stage of growth the athlete is in often helps understand proportional differences. For example:
   - growth of the legs finishes usually 1 to 2 years earlier than growth of the trunk so that coaches should expect disproportionately long legs very early in the growth spurt (thus difficulty with stoop-ins and Stalders etc.)
   - decreases in flexibility should be expected especially around the period of peak growth, and general skill decline due to the peak in height preceding the peak in weight / strength.
   - growth plates are weakest during the period of most rapid growth and since they are especially weak to shear forces, this period of most rapid growth is a period when skills which result in shear forces such as twisting saltos should be cautiously performed with considerable caution.

It seems to me that we should also be collecting basic anthropometric data on all of our athletes and maybe even showing coaches how to take these measurements 2 or 3 times per year so that they could determine for themselves when the athletes are beginning or peaking periods of rapid growth.

Part II X-rays for Status of Growth Plate Injuries

There have been several recent publications showing that wrist pain in gymnasts can be associated with growth plate damage to the distal radial epiphysis.[1,2,3,4,5,6,7,8,9,10,11]. The most interesting of these studies were the ones by our acquaintance Dr. John Aldridge who has travelled with the British Gymnastics team for several years. They carefully scanned the x-rays of their gymnasts' wrists and concluded that a large % of the athletes actually had growth plate damage which could easily be overlooked on normal x-ray reading. Having diagnosed the injury as a growth plate injury and not merely a soft tissue injury significantly changes the prognosis. The athlete's career is more at risk and the injury should be more carefully monitored in the case of growth plate injury vs. soft tissue injury.

Several of the studies reported that some of the injured athletes were forced to retire due to the growth plate injury. I can personally attest to this condition having watched Woody Dalrymple retire due to exactly this cause.

If we are to X-ray the boys wrists at nationals it would be possible for us to include a lateral view x-ray of any gymnasts who we suspected of having pain on the radial growth plate and carefully reading these x-rays as suggested by Carter and Aldridge. Any suspected results could be relayed through Dr. Ridder to the athlete's personal physician and coach.

Steps to Enable X-rays to be Taken at National Championships.

1. Permission from CGF
2. Permission from parents / coaches of athletes
3. Approval of Univ. of Sask. ethics committee
4. Financial arrangements secured.
5. Agreement of medical personnel involved.

1. Permission from CGF
   This could be approached at Elite Canada.

2. Permission from parents / coaches of athletes
   Letters would have to be sent out explaining the procedure, rationale, risks. (see attached sample Appendix A)

3. Approval of Univ. of Sask. ethics committee
   A proposal would have to be submitted to this committee for approval by April 24th.
4. Financial arrangements secured.
   • We **may** be able to arrange with the Dept. of Medical Imaging at Univ Hospital to be charged only for technicians time ($35.00 per hour). We can x-ray 10 or more boys per hour if we use times after 5:00 p.m. It is possible that the total cost of X-raying may only be $200.00 ??? It is possible that we may also have to pay for film which would be an additional $5.00 per athlete. ($150-200) but I'm quite sure that we would not be charged instrumentation time (bloody expensive)

   • As part of our responsibilities as a National High Performance Centre we would read the x-rays for skeletal age for no charge and we would enter the results into a data base and print out the results for athletes and coaches. (see Appendix B for sample).

   • Cost for additional x-ray taking and reading for athletes with suspected growth plate damage may be able to be absorbed in the above if Dr. Ridder agrees to help and if I can secure another physician here to help out. At the moment I am taking an orthopedics class and two of the instructors seem quite interested. One is an orthopedic surgeon specializing in hand surgery and the other is a pediatrics orthopod??

5. Agreement of medical personnel involved.
   • If Dr. Ridder agrees and if I can secure help from this end it would seem that this part is under control.

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Project Title:

Radiographic assessment of distal radial epiphyseal growth plates in male gymnasts who have been screened for possible growth plate damage.

1. Hypothesis

Several recent studies have demonstrated that wrist pain is common amongst gymnasts and that the incidence of growth plate damage in the distal radial epiphysis is higher than previously thought.

2. Academic Validity

The validity of this project has been endorsed by the following professionals:

- Dr. D. Ritter, an Ottawa orthopedic surgeon who is the Men's National Gymnastics Team Doctor and fellow member of the Sports Science Committee of the Canadian Gymnastics Federation.

- Dr. A. Dzus, a pediatric orthopedic surgeon at the Royal University Hospital in Saskatoon.

- Dr. S. Houston, a radiologist at Royal University Hospital in Saskatoon.

- Dr. D. Bailey, an internationally-respected researcher in the area of physical growth and development.

This project has been endorsed by:

- The Coaches Committee and the Men's Technical Committee of the Canadian Gymnastics Federation.

3. Funding

Funding is being provided by the Canadian Gymnastics Federation and Sport Canada.

4. Subjects

All male gymnasts in the Tyro (under 14), Novice (under 16) and Junior (16 and over) age categories at the National Gymnastics Championships will be invited to take part in the study.

5. Procedures

All athletes will undergo Test #1 (single X-ray to determine skeletal age) and Test #3 (KinCom measurement of leg strength). They will then be questioned about wrist pain and those with suspected growth plate involvement will be screened by Dr. Ritter. If he suspects growth plate injury, they will have three views of the wrists radiographed. (Test #2) These radiographs will be read by Dr. Ritter, Dr. Dzus and Dr. Houston and will be compared to a sample of radiographs from a similar study done in U.K.

6. Consent Forms

See attached.

7. Time Period

Testing will take place in the latter part of May, 1991.

8. Other Comments

In the 3-year study being conducted on the male gymnasts at the National High Performance Centre at the University of Saskatchewan, it has been found that 1/3 of the male gymnasts were more that one year delayed in their skeletal maturity. Late maturers have delayed fusion of epiphyseal and apophyseal growth plates (relative to early and average maturers), and therefore are at risk of growth plate injuries for a longer period of time. It is usual for gymnasts to experience wrist pain and this pain is often tolerated and accepted as normal. As a result, training is neither modified nor curtailed and subsequent injury to growth plates is more common that once thought. (see references on the enclosed documents)

UNIVERSITY ADVISORY COMMITTEE ON ETHICS IN HUMAN EXPERIMENTATION

Name and E.C. File #: K. Russell 91-69 May 6, 1991

Your project entitled: Radiographic assessment of distal radial epiphyseal growth plates in male gymnasts who have been screened for possible growth plate damage.

has been approved by the Committee.

1. Therefore you are free to proceed with the project subject to the following conditions:

   Approved.

2. Any significant changes of your protocol should be reported to the Director of Research Services for Committee consideration in advance of its implementation.

Sincerely,

Roland Muir

ROLAND MUIR
Director of Research Services
University of Saskatchewan

for Dr. E.A. McKenna, Chairman
University Advisory Committee on
Ethics in Human Experimentation

APPENDIX C

Skeletal Maturity

C.1. Sample data sheet with graph of inter-tester scores

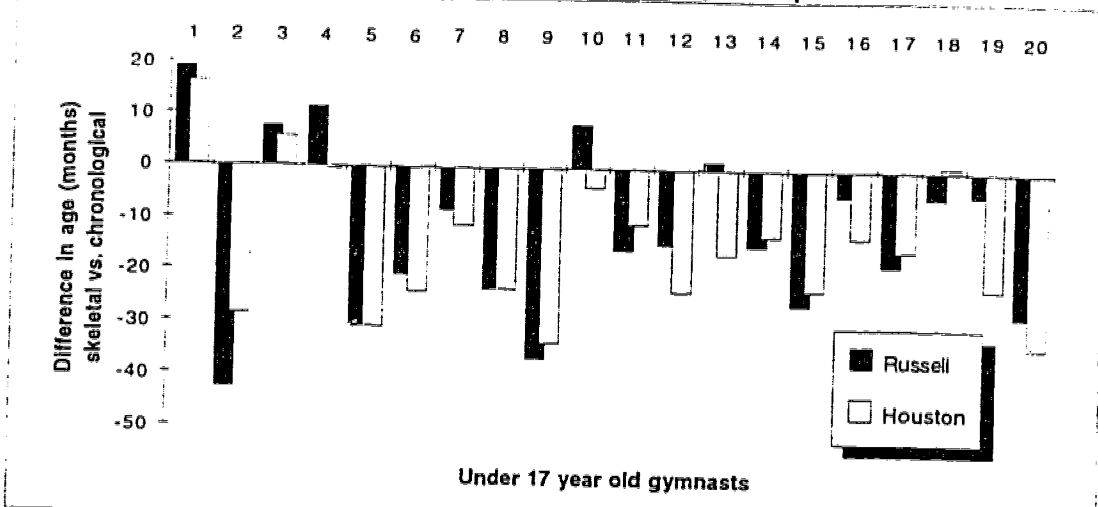
C.2. Scattergram of inter-tester scores used to calculate inter-tester reliability

C.3. Sample data collecting sheet used for establishing intra-tester reliability for reader "Russell"

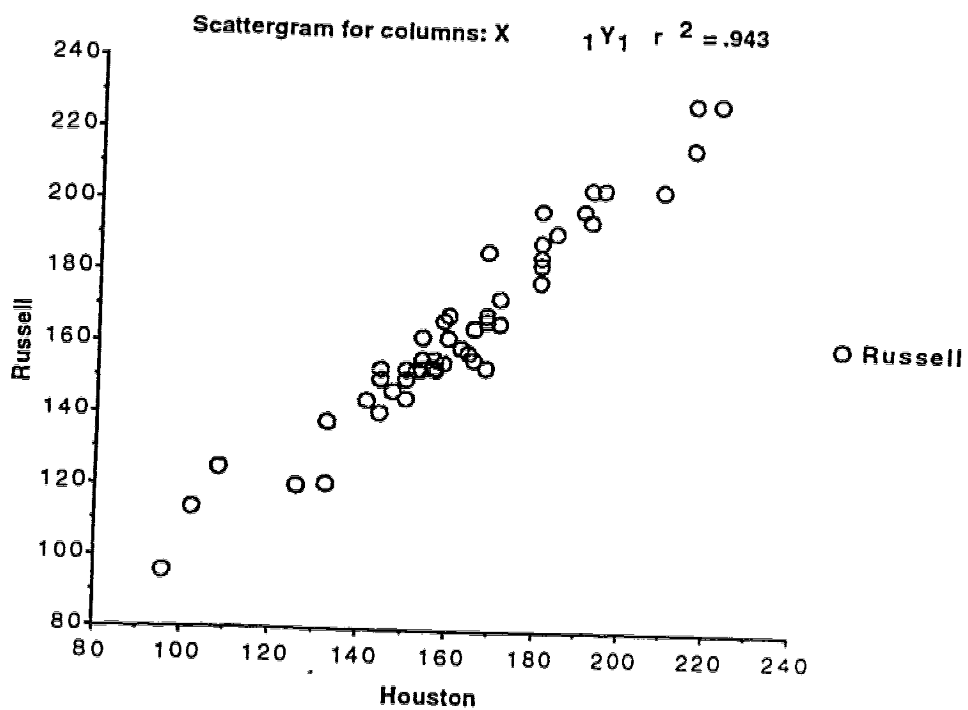
C.4. Sample letter to parents

C.5. Sample consent form

Skeletal Age - Male Gymnasts at the Canadian Championships



last name	age group	nat'l team	age months	Russell bone age	Russell diff.	Houston bone age	Houston diff.	diff. Houston Russell	mean diff chron. age skeletal age
	17		176	195	19	192	16	3	17.50
	17		197	154	-43	168	-29	-14	-36.00
	17		165	173	8	171	6	2	7.00
	17		193	204	11	192	-1	12	5.00
	17		184	153	-31	153	-31	0	-31.00
	17		177	156	-21	153	-24	3	-22.50
	17		191	183	-8	180	-11	3	-9.50
	17		191	168	-23	168	-23	0	-23.00
	17	age group	190	153	-37	156	-34	-3	-35.50
	17	age group	196	204	8	192	-4	12	2.00
	17		182	166	-16	171	-11	-5	-13.50
	17		182	167	-15	158	-24	9	-19.50
	17		196	198	2	180	-16	18	-7.00
	17		193	178	-15	180	-13	-2	-14.00
	17	junior	181	155	-26	158	-23	-3	-24.50
	17	age group	197	192	-5	184	-13	8	-9.00
	17		177	159	-18	162	-15	-3	-16.50
	17		163	158	-5	164	1	-6	-2.00
	17		191	186	-5	168	-23	18	-14.00
	17		178	150	-28	144	-34	6	-31.00
mean			185	173	-12	170	-15	3	-13.85
st dev			10	19	17	14	14	8	14.71
max			197	204	19	192	16	18	17.50
min			163	150	-43	144	-34	-14	-36.00
# of subj.			20	20	20	20	20	20	20.00
# of +'s					5		3	3	3.00
# of -'s					15		17	17	17.00
#≤-12 m					12		14	14	14.00
%≤-12 m					60%		70%		
#≤-24 m					5		6		
%≤-24 m					25%		30%		



Scatter plot of ages (in months) for calculating inter-tester reliability coefficient.

Count:	Covariance:	Correlation:	R-squared:
56	758.404	. 971	.943

Assessing Skeletal Age - Greulich - Pile

subject	Radius Ulna	capitate hamate triquet lunate	trapezium. trapezoid scaphoid	meta-carpals	phalanges	comments	age
#202	13 1/4	14	14	13 1/4	13 1/4	13 1/2	162
#200	11	10 1/2	10	11	11	10 3/4	179
#195	13	13 1/2	13 1/2	13	13	13 1/4	161
#189	10	10 1/2	10 1/2	11	11	10 1/2	136
#187	11	11 1/2	11 1/2	11 1/2	11 1/2	11 1/4	135
#186	13	13	13	13	12 1/2	12 3/4	X 153
#183	12 3/4	12 3/4	12 3/4	13	13	12 3/4	153
#179	12 1/2	12	12	12 1/2	11 1/2	12	145
#178	11 1/2	11	11 1/2	11 1/2	11 1/2	11 1/2	138
#177	12 1/2	12 1/2	12 1/2	12 1/2	12 1/2	12 1/2	150
145	10	10 1/2	10	10 1/2	10	S/-S 10 1/4	123
156	15	14	14	13	13	No sesamoid = 1 13.8	165

To: All Male Gymnasts (their Parents & Coaches) Competing at National Championships in Saskatoon, 1991

From: Keith Russell, Associate Professor, Univ. of Saskatchewan, Member, C.G.F. Sports Science Committee

The Men's National Team Program (Elite Planning Committee, Men's Program Committee and National Coach) is eager to have all current and prospective national team members included in a research initiative that will take place at the national championships. Therefore **all boys** attending the national championships in Saskatoon in May of 1991 are invited to take part in this study which will be conducted by a team of researchers who are presently involved in a 3 year research project of the male gymnasts at the National High Performance Centre for Men's Gymnastics at the University of Saskatchewan.

On the following pages are descriptions and information on three items we will test at the national championships. These tests are **voluntary**. If you wish to take part **you must sign the consent form**.

- test # 1 and # 2, the wrist X-rays, will take approximately 15 minutes
- test # 3, the leg strength test, will take approximately 15 minutes.
- Both tests will be conducted on campus, within 5 min. walk of residences

To be part of this research project you must sign this consent form and **send it with your other national championships documentation.**

Or Mail to: Keith Russell
College of Physical Education
University of Saskatchewan
Saskatoon, Sask. S7N 0W0

If you have any questions call collect to Keith Russell 306 966 6505 or 329 4246

Test #1. Determining the Skeletal Age of Each Gymnast

A single x-ray of one wrist is the most accurate method available to determine a child's skeletal age. We can then compare this to his chronological age (birth to present) and tell whether a boy is maturing at an average rate or if he is an early maturer or late maturer.

In the Saskatoon study we have found that 1/3 of the competitive male gymnasts are late maturers. That is, their skeletal age is delayed 12 months or more compared to their chronological age. In fact, several of our gymnasts (pre teens and early teens) are 2 years delayed in their skeletal development. While a 2 year delay in maturation is absolutely normal, it is unusual to have such a high number of late maturers in a sample of 50 boys.

Previous research has established that this is the usual pattern in groups of female gymnasts, but there is little research on males. We would like to determine the skeletal age of each gymnast and give this information to coaches and parents so they can synchronize training loads and growth patterns. Then we would like to calculate what percentage of national level male gymnasts are late maturers.

<u>Of what interest is this to athletes, parents and coaches?</u>

- until the skeleton is fully matured, growth occurs in cartilaginous growth plates near the ends of long bones. Also, small bones such as in the wrist are progressively changing from cartilage to bone. These growth plates and cartilaginous bones are the most vulnerable areas of the skeleton to injury.

- slow or late maturing boys possess these growth plates <u>for a longer period of time</u> than do early maturing boys and are therefore vulnerable to growth plate injury for a longer period of time.

- by informing athletes of their skeletal age we can forewarn them of any potential vulnerability and suggest how coaches could monitor their growth.

- Look at the last page for the feedback sheet we are giving the gymnasts in the research project at University of Sask. We would give the same feedback to the male athletes and their coaches at national championships.

Jim Nast

Birth Date	03-27-78	**Age at X-ray**	146 months
minus		minus	
X-ray Date	06-01-90	**Skeletal Age**	120 months
equals		equals	
Age at X-ray	146 months	**Difference**	-26 months

Interpretation of X-Ray Results

The above results represent the skeletal age of your son as compared to his chronological age. The skeletal age (or biological age) is determined by "reading" wrist X-rays and is considered the most accurate method available. All healthy children will show the same *pattern of growth* but their *tempo* will vary considerably. For example, boys who are very early maturers will begin their adolescent growth spurt as early as 10½ while boys who are very late maturers will not begin until they are 14½. Similarily, the peak rate of growth occurs, on the average, at 14 years of age but can vary by plus or minus 2 years. These are all **normal.**

By establishing each boy's skeletal age we are able to compare his results on strength and flexibility, etc. with other gymnasts of his same age and/or his same physical maturity. This will be particularly interesting with respect to studying injury patterns.

We would also like to help coaches and athletes by pointing out some possible consequences of various maturation differences. For example:

- early maturing boys tend to excel early in the sport and then often are discouraged when their peers catch up. Similarily, late maturing boys are often discouraged as their peers mature more quickly.
- Prior to puberty boys legs grow faster than their trunks, while during the growth spurt the opposite is true. As coaches are made aware of this they will be able to monitor whether learning of new skills or maintenance of learned skills is affected by these differential growth rates. (As one text book puts it..."a boy stops growing out of his trousers a year before he stops growing out of his jackets").
- In most cases, maturity status (early or late) is independent of adult size (an early maturing boy may be tall, average or short). This is true of a late maturing boy as well.

Consent Form

To be part of this research project you must sign this consent form and **send it with your other national championships documentation.**

Or Mail to: Keith Russell
College of Physical Education
University of Saskatchewan
Saskatoon, Sask. S7N 0W0

If you have any questions call collect to Keith Russell 306 966 6505 or 329 4246

Rights and Welfare of the Individual

X-ray imaging is routinely used in the modern practice of medicine and involves no pain, there is minimal radiation risk, and the site being measured (wrist) is well away from vital organs. Your identity will remain confidential and only those directly involved with the study (investigators and medical staff) will have access to your (son's) records and results.

Subjects Statement

I voluntarily consent to participate in this study. I understand that I am free to withdraw at any time, from any part of the study, without jeopardizing any of my medical management or national team opportunities. The procedures have been fully explained to me and I fully understand the contents of the consent form, the proposed procedures and the possible risks.

I have had an opportunity to ask questions and have received satisfactory answers to all inquiries regarding this study.

Name of gymnast ____________________
Name of parent ____________________
Full Mail Address ____________________
____
____

yes	no	
☐	☐	**All Tests**
☐	☐	**Test #1**
☐	☐	**Test #2**
☐	☐	**Test #3**

date __________ Signature of subject ____________________
date __________ Signature of parent ____________________
date __________ Signature of witness ____________________