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From Tradition To Tomorrow

## Primary Periphyseal Stress Injuries in Young Athletes



# Outline

Background
Methods
Results
Conclusions





• My interest in the effects of physical activity on the growing skeleton dates back to my days as a graduate student at UBC (1976-78).



 I was particularly interested in the effects of excessive loading on lower extremity bone growth in young distance runners.



- While physical activity has a beneficial effect on the growing skeleton, there is evidence that excessive physical loading might disrupt skeletal growth
- Results from animal studies show that prolonged intense physical loading may inhibit or stop bone growth.
  - LeVeau BF, Bernhardt DB. Developmental biomechanics. Effects of forces on the growth, development and maintenance of the human body. *Phys Ther* 1984



- Could the stress of running long distances overwhelm the integrity of the primary physes in the lower extremities of young runners?
- What is the incidence and severity of primary physeal injuries affecting the lower extremities of young runners?

### Growth Plate Injury: A Threat to Young Distance Runners?

#### Dennis J. Caine, MEd Koenraad J. Lindner, PhD

In brief: As more children and adolescents participate in long-distance running and rigorous training, the possibility of resulting growth plate damage has become a concern. The research literature indicates a need for caution, but no data unequivocally pronounce long-distance running safe or harmful to the developing child. Longterm effects should be studied by examining incidence reports on growth plate injuries, statistically analyzing running-related injuries, and examining youngsters who now participate or have participated in intense long-distance running. The authors emphasize that damage to the growth plate should be avoided through early diagnosis and treatment.

oday children are participating in organized sports earlier and in greater numbers than ever before. Long-distance running is no exception. Sixyear-old children completing marathon races no longer attracts major attention. Lopez and Pruett<sup>1</sup> stated that training for these children may include 10 to 15 miles of running per day and perhaps 80 miles a week.

Popular opinions range from the position that running is natural for the child<sup>2</sup> to serious questioning of the suitability of marathon races for youngsters.<sup>3</sup> However, physicians, educators, and scientists have been less opinionated in view of the dearth of scientific evidence. Some are confident that the normal, healthy *continued* 

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Case report: A 15 year-old male cross-country runner who had been running 50 miles per week and developed chronic knee pain. A stress fracture of the proximal tibial epiphysis of the Salter-Harris type, similar to that seen in the proximal humerus of baseball pitchers. Cahill BR. Stress fracture of the proximal tibial epiphysis: a case report. *Am J Sport Med* 

### 1977.

- Doctoral studies at the University of Oregon, beginning in 1980
- Collaboration with Steven Roy, MD, Director, Sports Injuries and Running Clinic of Eugene, P.C.
  - Possible dissertation topic?



• Although Dr. Roy wasn't at that time seeing young runners with stress-related primary physeal injuries (PPSIs) in his medical practice, he was treating young gymnasts with painful wrists.



• Over a period of three years (1980-83), 21 M/F gymnasts, ages 10-17 years with chronic wrist pain were seen

• 11 of these gymnasts were diagnosed with stress reaction or stress fracture of the distal radial growth plate 0363-5465/55/1305-0301\$02.00/0 THE AMERICAN JOURNAL OF SPORTS MEDICINE, Vol. 13, No. 5 © 1985 American Orthopaedic Society for Sports Medicine

### Stress changes of the distal radial epiphysis in young gymnasts

#### A report of twenty-one cases and a review of the literature

STEVEN ROY,\* MB, ChB, DENNIS CAINE, MEd, AND KENNETH M. SINGER, MD

From Sports Injuries and Running Clinic, and Orthopaedic and Fracture Clinic, Eugene, Oregon

#### ABSTRACT

Between 1980 and 1983, 21 young, high-performance gymnasts with stress changes related to the distal radial epiphysis, were treated and followed for a mean of 24 months (range, 6 to 42 months). Eleven of the gymnasts presented with roentgenographic changes of the distal radial epiphysis, and in these recovery took at least 3 months. This group was compared to a group of ten gymnasts who had similar symptoms but no roentgenographic changes, and who recovered within an average of 4 weeks.

The roentgenographic changes, which are described in detail, are considered to represent stress changes, possibly stress fractures, of the distal radial epiphysis. No residual growth-related problems have been observed. Possible etiologic factors are discussed, and the literature as it pertains to stress-related adaptation and injury in the growing athlete is reviewed.

Organized gymnastics, particularly women's gymnastics, is currently enjoying a dramatic increase in the number of its participants. It has been estimated that over 600,000 individuals are involved in gymnastics in the United States, either through school teams or as club members. Not only is the number of participants rising, but children are entering the sport at increasingly younger ages.

Associated with the trend toward earlier participation is the increased intensity of training, resulting in unprecedented levels of musculoskeletal loading and stress. Therefore, the study of the adaptive potential of growing bone and soft tissues in the young gymnast is an important one. Of particular concern is the question of whether the tolerance limits of the growing structures could be exceeded by the specific and frequent demands of the sport.

In gymnastics, the upper extremities are used as weightbearing limbs. Even so, acute wrist injuries occur infrequently, and overuse injuries are rarely described. In the past few years, however, a number of gymnasts complaining of wrist pain have come to our attention, some of whom have had roentgenographic changes involving the distal radial epiphysis. The purpose of this paper is to report on these changes, and to draw the attention of physicians and others involved in the health management of gymnasts to the existence of epiphyseal stress changes as one of the causes for the production of symptoms of wrist pain.

#### MATERIALS AND METHODS

Between 1980 and 1983, 21 gymnasts, all of whom were from a nationally known academy of artistic gymnastics, presented complaining of wrist pain which was clinically and roentgenographically evaluated, and considered to be due to stress-related changes of the distal radial epiphysis. All cases of acute wrist fracture, acute sprains, tendinitis, synovial cysts, and joint dysfunction were excluded from this study.

The mean age of the gymnasts at the time of injury was 12 years, the youngest being 10 and the oldest 17 years old. Nineteen of the gymnasts were girls. Of the 21, 17 worked out at least 6 hours a day, 6 days a week, and were of a Class II, Class I, or Elite level (see Table 1). The other four participated an average of 3 hours, 3 days a week. Of the gymnasts injured, eight had involvement of both wrists, seven had symptoms of the right wrist alone, while in six only the left was symptomatic.

Significant roentgenographic findings were present in 11 of the gymnasts. In the absence of roentgenographic findings, the diagnosis of a stress reaction was made based on the following clinical criteria: there was no acute trauma to the wrists; pain and limitation of dorsiflexion, in particular,

<sup>\*</sup> Address correspondence and reprint requests to: Steven Roy, MB, ChB, Sports Injuries and Running Clinic of Eugene, P.C., 132 East Broadway, Suite 830, Eugene, OR 97401.

- Radiographic changes seen include widening of the radial margin of the distal radius physis and irregularity of the metaphyseal margin
  - Roy et al. Stress changes of the distal radial epiphysis in young gymnasts. Am J Sports Med 1985







- We now understand that stressrelated epiphyseal plate widening begins in the metaphysis with disruption of the normal blood supply. Widening of the physis then develops as the chondrocytes continue to transition from the germinal layers to the proliferative zone, whey they accumulate because they cannot calcify.
  - Laor et al. Physeal widening in the knee due to stress injury in child athletes. *Am J Roentgenol* 2006.

Anatomy of the growth plate (physis)



- The widening of the growth plate is usually temporary. However, there may be an associated stressrelated injury of the epiphysis which may further compromise blood supply to the physis and, in extreme cases, lead to osseous necrosis and deformity with the developing ossification center and to growth irregularities in the physis.
  - Bedoya et al. Overuse injuries in children. *Top Magn Reson Imag* 2015



Left hand of 15-year-old male climber who undertook intensive finger strength exercises and ignored medical advice, permanently damaging epiphyseal plate of proximal interphalangeal joint in middle finger. Morrison A B, Schöffl V R Br J Sports Med 2007

• Since overuse injuries may involve one or more constituents of the epiphyseal-physealmetaphyseal complex, it make sense to collectively refer to them as "primary periphyseal stress *injuries,*" or PPSIs.



- Trends in youth sports since the 1980's...
  - increased duration and intensity of physical loading
  - Earlier specialization and year-round training
  - Increased difficulty of skills practiced



• Children and adolescents are also increasingly visiting wilderness recreational destinations and participating in a growing number of adventure and extreme sports.



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Topics covered: aquatic adventure sport, all-terrain vehicles, motocross, mountain biking, rock climbing, rodeo, skateboarding, skiing, snowboarding, wilderness and extreme environments, and injury prevention.

### RESEARCH IN Sports medicine

### An International Journal

#### EDITOR-IN-CHIEF Youlian Hong

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Included in this print edition: Supplement 1 Special Issue: Epidemiology of Youth Injury in Adventure and Extreme Sports Guest Editors: Dennis J. Caine and Aaron J. Provance



 National and international sport competitions for adolescents, including the Youth Olympic Games, are also helping to drive the popularity of sports among youth.



- Year-round participation in youth sports which involve high levels of repetitive training fosters an environment where overuse injuries are likely to occur.
  - DiFiori J. Overuse injury of the physis: a "growing" problem. Clin J Sport Med 2010



• The concern is that the mechanical tolerance of growing bones may be exceeded by the intense and continuous training characteristic of many youth sports today



# Purpose of this presentation...

• To provide an update and current understanding of the occurrence and outcome of PPSIs in young athletes...what is the nature and size of the problem!



# SYSTEMATIC REVIEW

# 2. Methods

## 2. Methods

- The search was limited to published peer-reviewed reports
  - case reports and case series
  - cross-sectional
  - case-control
  - cohort studies
- <u>The search yielded</u> <u>126 articles with</u> <u>relevant data</u>

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.



# 3. Results



## 3. Results

• 126 original published scientific articles • 101 Case reports/case series • 17 Cross-sectional studies • 1 Case-control • 7 Cohort studies





Fig 2. Primary periphyseal stress injuries (PPSIs): frequency of reports published per decade (1950-2019). NOTE: 3 articles published in 2020 are not included in this figure.

## 3. Results Organization

- 3.1 Case reports and case series
- 3.2 Cross-sectional studies
- 3.3 Cohort studies
- 3.4 Injury outcome
  - 3.4.1 Injury management
  - 3.4.2 Growth disturbance and deformity
  - 3.4.3 Surgery
  - 3.4.4 Long-term health outcome



## 3.1 Case Reports/Case Series

	No. of reports	No. of patients with PPSIs
Shoulder (1953-2019)	33	197
Elbow (1975-2019)	8	47
Wrist (1981-2019)	28	98
Hand/fingers (1997-2019)	11	80
Knee (1977-2019)	13	26
Ankle/foot (1980-2019)	8	25
	101	473

## Shoulder PPSI

- Little league shoulder: an overuse condition that affects the proximal humerus of the throwing arm.
  - Dotter, 1953
- "LLS" is believed to stem from chronic repetitive shear, torque or traction forces imposed on the unossified cartilage of the proximal humeral physis."

• Heyworth et al., 2016



## Shoulder PPSIs (191M; 6F)

- Baseball (n=185 patients)
- Other (n=12 patients)
  - Badminton
  - Cricket
  - Football
  - Gymnastics
  - Tennis
  - Swimming
  - Volleyball



## Shoulder PPSI (proximal humerus)

- A 13-year-old boy, a baseball pitcher, who presented with right shoulder pain while throwing
- **Top,** External oblique right shoulder radiograph shows widening, irregularity and fragmentation of the proximal humeral physis.
- Bottom, Éxternal oblique left shoulder radiograph
  - Anton et al. Little league shoulder: a growth plate injury. Pediatr Radiol, 2010.



## Shoulder PPSIs

- Annual volume of diagnosed Little League shoulder cases over 15-year study period, in 3-year periods.
  - Heyworth et al. Trends in the Presentation, Management, and Outcomes of Little League Shoulder. *Am J Sports Med* 2016.



## Elbow PPSI (proximal radius)

 In gymnastics, full extension loading causes maximal compression forces to be transmitted through the lateral aspect of the radial head which can lead to stress fractures of the radial head epiphysis • Santelli et al., 2019



## Elbow PPSIs (26M, 21F)

- Proximal radius
  - Baseball (4 patients)
  - Gymnastics (41 patients)
- Distal humerus PPSI
  - Baseball (1 patient)
  - Gymnastics (1 patient)


### Elbow PPSI (Proximal radius)

- Radiograph demonstrating a Salter–Harris IV stress fracture of right radial head in an 11-year-old female gymnast presenting with right elbow pain.
  - Santelli et al. Proximal radial head fractures in young gymnasts. *Clin J Sport Med* 2019



## Wrist PPSI (distal radius)

• The distal radius is a common site for injury in gymnasts because of the significant amount of compressive and rotational forces on the forearm during upper extremity weightbearing.



Wrist PPSIs (33M, 65F)

- Gymnastics (95 patients)
- Other (3 patients)
  - Badminton
  - Break dancingClimbing



### Wrist PPSI

- 12-year-old female gymnast with chronic physeal injury with fraying, widening and irregularity of the phyis
- Note low-signal intrusions into metaphysis typical of focal failure of ossification of physeal cartilage (arrow)
  - Dwek J. MR imaging of overuse injuries in the skeletally immature gymnast: spectrum of soft-tissue and osseous lesions in the hand and wrist. *Pediatr Radiol*. 2009



## Finger PPSIs

- In climbing, the greatest finger tip forces are applied to the middle finger, followed by the ring finger. The most frequent PPSI reported among young climbers involves the dorsal aspect of the middle phalanx, with injury to the middle finger being most common
  - Quane et al. Effect of simulated rock climbing finger postures on force sharing among the fingers. Clin Biomech 2003.



# Hand/Fingers PPSIs (65M, 15F)

GymnasticsHand (2 patients)

Rock Climbing Fingers (78 patients)



## Finger PPSIs

- A 15-year-old male youth with a 1week history of bilateral painful swelling of the proximal interphalangeal joints of the middle fingers.
- **Figure 1.** Anteroposterior (A) and lateral (B) radiographs of right middle finger showing a displaced Salter-Harris type III fracture of the basal epiphysis of the middle phalanx.
- **Figure 2.** Follow-up lateral radiograph showing fracture union and the start of epiphyseal closure.
  - Chell et al. Bilateral Fractures of the Middle Phalanx of the Middle Finger in an Adolescent Climber. Am J Sports Med 1999



### Knee PPSIs

• These injuries are believed to result from repeated compression, rotational, shearing, valgus or varus forces of the knee ensuing from repetitive trauma during sports activities.



### Knee PPSIs (17M,9F)

- Baseball (1 patient)
- Basketball (3 patients)
- Gymnastics (2 patients)
- Multiple (13 patients)
- Recreational (1 patient)
- Rugby (1 patient)
- Running (1 patient)
- Soccer (3 patients)
- Tennis (1 patient)



### Knee PPSI (proximal tibia)

- A 15-year-old rugby player who had been intensely practicing his kicking skills in spite of increasing pain and swelling
- Radiographs show wide separation of right proximal tibial epiphysis, asymmetrically affecting the medial side more than the lateral side.
  - Nanni et al. Stress-induced Salter-Harris I growth plate injury of the proximal tibia. *Skeletal Radio* 2005.

Ankle/Foot PPSIs (2M, 5F, 18 M/F)

- Basketball (1 patient)
- Dance (4 patients)
- Distance running (1 patient)
- Multiple sports (18 patients)
- Soccer (1 patient)



### Ankle PPSI (distal tibia)

- A 9-year-old female recreational dancer and gymnast with a 2-month history of progressive right ankle pain.
  - A, Bilateral anteroposterior views.
  - **B**, Bilateral lateral views.
  - C, Magnification of the anteroposterior radiograph of the right ankle, showing metaphyseal cystic changes and widening of the distal tibial physis
    - Bernholdt et al. Stress fracture of the distal tibial physis in an adolescent recreational dancer. Am J Sports Med. 2013; 41: 1649-1652.



### Foot PPSI (proximal phalange)

- A 10-year-old ballet dancer girl with a history of 5 months of bilateral foot pain. Plain radiographs of the feet show segmentation of the epiphysis of the proximal phalanges of the first toe on both sides
  - Csonka et al. Operative management of bilateral Salter-Harris type III fractures of the proximal phalanges of the great toes of a 10-year-ol female ballet dancer: a case report. J Pediatr Orthop B. 2016.



### 3.1 Case Reports and Case Series

- Case reports and case series are numerator-based and therefore cannot be used to generate incidence rates of PPSIs.
- However, they can be used to provide useful information about the existence and relative frequency of this condition, preferring for successful treatments, and clinical outcome

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### A report of twenty-one cases and a review of the literature

STEVEN ROY,\* MB, ChB, DENNIS CAINE, MEd, AND KENNETH M. SINGER, MD

From Sports Injuries and Running Clinic, and Orthopaedic and Fracture Clinic, Eugene, Oregon

### ABSTRACT

Between 1980 and 1983, 21 young, high-performance gymnasts with stress changes related to the distal radial epiphysis, were treated and followed for a mean of 24 months (range, 6 to 42 months). Eleven of the gymnasts presented with roentgenographic changes of the distal radial epiphysis, and in these recovery took at least 3 months. This group was compared to a group of ten gymnasts who had similar symptoms but no roentgenographic changes, and who recovered within an average of 4 weeks.

The roentgenographic changes, which are described in detail, are considered to represent stress changes, possibly stress fractures, of the distal radial epiphysis. No residual growth-related problems have been observed. Possible etiologic factors are discussed, and the literature as it pertains to stress-related adaptation and injury in the growing athlete is reviewed.

Organized gymnastics, particularly women's gymnastics, is currently enjoying a dramatic increase in the number of its participants. It has been estimated that over 600,000 individuals are involved in gymnastics in the United States, either through school teams or as club members. Not only is the number of participants rising, but children are entering the sport at increasingly younger ages.

Associated with the trend toward earlier participation is the increased intensity of training, resulting in unprecedented levels of musculoskeletal loading and stress. Therefore, the study of the adaptive potential of growing bone and soft tissues in the young gymnast is an important one. Of particular concern is the question of whether the tolerance limits of the growing structures could be exceeded by the specific and frequent demands of the sport.

In gymnastics, the upper extremities are used as weightbearing limbs. Even so, acute wrist injuries occur infrequently, and overuse injuries are rarely described. In the past few years, however, a number of gymnasts complaining of wrist pain have come to our attention, some of whom have had roentgenographic changes involving the distal radial epiphysis. The purpose of this paper is to report on these changes, and to draw the attention of physicians and others involved in the health management of gymnasts to the existence of epiphyseal stress changes as one of the causes for the production of symptoms of wrist pain.

### MATERIALS AND METHODS

Between 1980 and 1983, 21 gymnasts, all of whom were from a nationally known academy of artistic gymnastics, presented complaining of wrist pain which was clinically and roentgenographically evaluated, and considered to be due to stress-related changes of the distal radial epiphysis. All cases of acute wrist fracture, acute sprains, tendinitis, synovial cysts, and joint dysfunction were excluded from this study.

The mean age of the gymnasts at the time of injury was 12 years, the youngest being 10 and the oldest 17 years old. Nineteen of the gymnasts were girls. Of the 21, 17 worked out at least 6 hours a day, 6 days a week, and were of a Class II, Class I, or Elite level (see Table 1). The other four participated an average of 3 hours, 3 days a week. Of the gymnasts injured, eight had involvement of both wrists, seven had symptoms of the right wrist alone, while in six only the left was symptomatic.

Significant roentgenographic findings were present in 11 of the gymnasts. In the absence of roentgenographic findings, the diagnosis of a stress reaction was made based on the following clinical criteria: there was no acute trauma to the wrists; pain and limitation of dorsiflexion, in particular,

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# 3.2 Cross-sectional studies

 Descriptive cross-sectional studies simply characterized the prevalence of a health outcome at either one point in time or over a period of time. For example, it take a "snapshot" of the proportion of individuals in population that are, for example, injured or non-injured at one point in time.



# 3.2 Cross-sectional studies

- Seventeen cross-sectional studies provided prevalence estimates of PPSIs involving the shoulder, wrist and fingers among baseball players, gymnasts, and climbers.
- Notably, none of the studies reported on lower extremity PPSI among young athletes.



### Prevalence of PPSIs

Sport	No. Subjects with PPSSs	Total no. of subjects	Overall Prevalence
Baseball (3 studies of shoulder)	287	2163	13.2%
Diving (1 study of wrist)	20	38	52.6%
Gymnastics (9 studies of wrist)	212	687	30.9%
Climbing (4 studies of fingers)	30	96	31.2%

### 3.2 Cross-sectional studies

- What is the prevalence of stress changes of the distal radial growth plate?
  - Sixty young gymnasts (39 females, 21 males) were xrayed (Winter, 1986)
  - Radiographic evaluation revealed 5 gymnasts (4 girls, 1 boy) with stress-related changes of the distal radial growth plate (8.3%)

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### Stress changes of the distal radial growth plate

### A radiographic survey and review of the literature

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From the \*Department of Exercise and Movement Science, University of Oregon, ‡Sports Injury Clinic, and §Orthopedic and Fracture Clinic, Eugene, Oregon

### ABSTRACT

We conducted a radiographic survey to determine skeletal age and the nature and prevalence of stress-related changes affecting the distal radial growth plate in 60 young competitive gymnasts (39 females, 21 males). Comparison of results for chronological and skeletal age revealed a significant delay in maturation for girls (P < 0.001). Radiographic evaluation revealed 5 gymnasts (4 girls and 1 boy) with stress-related changes of the left wrist, and four of these were considered to be minimal.

These results, in conjunction with our previous findings and the review of related literature, reveal three important observations. First, the widening and irregularities of the distal radial physis that we described previously appear to be the first in a spectrum of abnormal changes secondary to overuse and probably represent a stress fracture of the distal radial growth plate. The radiographic changes associated with this injury are not the normal adaptive changes seen in young, competitive gymnasts.

Secondly, more serious long-term abnormality may result even though the injury may initially resemble a Salter-Harris type I or II stress fracture. Long-term complications may include symmetrical or asymmetrical retardation or halted growth at the affected site, positive ulnar variance, and associated pathoanatomic sequelae. Thirdly, the incidence of distal radial growth plate stress injury remains unclear; we recommend a further, large-scale prospective epidemiologic study in-

† Address correspondence and reprint requests to: Dennis Caine, PhD, Department of Physical Education, Health, and Recreation, Western Washington University, Bellingham, WA 98225–9067. || Deceased, October 7, 1991. volving both male and female gymnasts. We urge that physicians and other health professionals associated with gymnastics clubs educate coaches about the possibility of significant injury to the distal radial physis, risk factors, and suggested preventive measures.

Children and adolescents are participating in gymnastics in greater numbers and at earlier ages than ever before. Often the training regimens for these young athletes are characterized by extremely high duration and levels of intensity. For example, the junior elite female gymnast (10 to 14 years) is reported to train, on the average, 27 hours per week.<sup>35</sup> Top-level Chinese gymnasts are reported to train as many as 60 hours per week.<sup>20</sup> Because of this increased physical loading, studying the adaptive potential of the growing bones of young gymnasts is extremely important. Basic to such investigation is the concern that the tolerance limits of the growth plate may be exceeded by the extent and frequency of the physical demands.<sup>12</sup>

Unlike most other sports, in gymnastics the upper extremities are used as weightbearing limbs. The wrist in particular is the site of tremendous physical loading. Examples of stress-inducing activities include the repetitive execution of handsprings; vaulting and beam skills; and supporting, hanging, and twisting maneuvers on the bar apparatus. Both compression and rotational forces are inherent in these activities. Because this series of loads is mainly borne by the distal end of the radius at its interface with the wrist, it is not surprising that injury at this site often involves the distal radial growth plate.<sup>13</sup>

Between 1980 and 1983 we studied 21 high-performance gymnasts, 19 females and 2 males, with stress changes related to the distal radial growth plate.<sup>32</sup> Eleven of these gymnasts presented with radiographic changes of the distal

# PPSI's associated with growth disturbance in cross-sectional research

Study	Sport	No. patients	Diagnosis
Chang et al., 1995	Gymnastics	3	Early partial closure of the distal radial physis
Shih et al., 1995	Chinese Opera	2	Early partial closure of the distal radial physis
Schlegal et al.,2002	Rock climbing	1	Premature closure of the proximal phalanx of the thumb
Garcia et al.,2018	Rock climbing	1	Early physeal bone bridging of the proximal IP joint of middle finger
Bartschi et al. 2019	Rock climbing	8	Joint incongruity with permanent impairment of the PIP joint of the middle finger (8 climbers)

## 3.3 Cohort studies

- Unfortunately, most cohort studies of injuries affecting young athletes provide few details about overuse injuries, including PPSIs
- Our search uncovered only a handful of cohort studies which report on upper extremity PPSIs among young athletes.



### Prospective Cohort Studies

Study	Sport	# Subjects	Age	Outcome
Holt et al., 2020	Baseball (1 season)	23M	10-12	1/23 cases of LLS
Lishen & Jianhua, 1983	Gymnastics (9 years)	18F, 10M	10-19	14/28 cases of distal radius PPSI
Caine et al., 1989	Gymnastics (1 year)	50F	10-17	4/50 cases of distal radius PPSI
Dixon & Fricker, 1993	Gymnastics (9 years)	74F	9-19	3/74 cases of distal radius PPSI
Schoffl et al., 2007	Climbing (5 years)	6M, 4F	16-21	8/10 cases of PPSIs involving the fingers

### 3.3. Cohort Studies

- Descriptive findings:
  - Gymnasts trained 40,127 hours; the overall injury rate was 3.66 injuries per 1000 hours exposure
  - 43/50 gymnasts sustained 147 injuries
  - More than half of injuries were overuse injuries
  - 4/147 injuries were PPSI's involving the distal radius

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### An epidemiologic investigation of injuries affecting young competitive female gymnasts

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### ABSTRACT

A prospective study of injuries affecting 50 highly competitive young female gymnasts was conducted over a period of 1 year. Many of the findings of this investigation were consistent with previous studies and suggest particular injury trends in women's gymnastics. These results included injury location, injury severity, nature of onset, event, and activity at the time of injury. Some of the descriptive results, however, provided information that was heretofore unreported or inconsistent with previous investigations. These findings involved injury rate, reinjury rate, time loss, injury type, hours of practice, and incidence of physician-seen injuries. Some of these findings were disturbing and echo concerns registered in the professional literature. In particular, the reinjury rate is alarming and points to the need for complete rehabilitation before return to full participation. The results of the analytic component of the study alluded to the potential role of competitive level and maturation rate in the profile of the injuryprone gymnast. Specifically, rapid periods of growth and advanced levels of training and competition appeared to be related to injury proneness. Pursuant to the descriptive and analytic results of the investigation, recommendations for injury prevention and continued research are made.

Children are participating in organized sports at earlier ages and in increasing numbers. This trend is particularly evident in women's gymnastics. According to one source,<sup>10</sup> this sport experienced an increase of 461% in interscholastic participants in the United States between 1974 and 1980. Since 1980, however, the number of interscholastic participants has been decreasing while the number of clubs, and consequently younger participants, has been increasing dramatically.<sup>14</sup> Early participation has become characteristic of women's gymnastics; the average age of champions and Olympic gold medal winners has decreased markedly over the past 2 decades.

The trends of earlier participation and increased numbers of participants have been accompanied by increased levels of training. For example, the junior elite female gymnast (i.e., 10 to 14 years of age) is reported to train, on the average, 5.36 days per week and 5.04 hours per day.<sup>25</sup> Unfortunately, a growing body of evidence suggests that the processes of growth, particularly those associated with periods of rapid growth, render the young female gymnast more susceptible to injury than the postpubescent who characterized the sport less than 2 decades ago.<sup>6</sup>

Increased involvement at an early age, with the extreme training intensity required, strongly suggests the possibility of a concomitant increase in the risk of injury. Given the uncertain long-term consequences of pediatric sports injuries and the rising costs of medical care, injury prevention would seem to be of utmost importance. Therefore, reasonable questions to ask include the following: 1) What are the nature and rate of injuries affecting young female gymnasts, and 2) to what extent are such injuries preventable?

The accumulating reports of injuries to young female gymnasts against a background of their apparent vulnerability to such insult indicate an active concern for their welfare. However, an extensive review of the literature pertaining to the epidemiology of gymnastics injuries reveals more questions than answers.<sup>10</sup> The purpose of this investigation was to determine the following: 1) What are the nature and rate of injuries that affect young competitive

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### 3.3 Cohort Studies

- 6.1% of the injuries sustained were primary physeal injuries
  - 5 apophyseal injuries
  - 2 physeal stress injuries
  - 2 physeal fractures
  - Caine et al. Epidemiology of injuries affecting young competitive female gymnasts. *Am J Sports Med*. 1989.



## Nine-Year Study: 14 of 28 top-level Chinese gymnasts developed progressive wrist pathology

	Clinical Characteristics	<b>Radiographic Characteristics</b>
Stage I	Wrist pain associated with upper extremity weight-bearing	No abnormalities seen
Stage II	Decreased range of motion at the wrist	Stress-related changes of the distal radial growth plate
Stage III	Wrist function is limited	A relatively lengthened ulna; wrist joint presents with arthritic changes



Source: Lishen Q, Jianhua O. Epiphyseal injury in gymnasts. *Chinese J Sports Med* 1983;2:7-12.

Source: Mandelbaum et al. *Am J Sports Med* 1989 3.4 Injury outcome

- 3.4.1 Injury management
  3.4.2 Growth disturbance and deformity
  3.4.3 Surgery
  3.4.4 Long-
- 3.4.4 Longterm health outcome



### 3.4.1 Injury Management

- In the case literature, PPSIs were generally treated with complete rest from the exacerbating activity to allow healing.
- Time off sport before return to activity ranged from 1-12 months depending on timing of treatment relative to injury onset and patient compliance



### 3.4.1 Injury Management

• Studies report the use of various treatment modalities to ensure rest of the affected structure, including use of a sling, casting, crutches, knee immobilizers, ankle brace, and shoe modification



### 3.4.1 Injury management

 Many studies also report the use of physical therapy and related programs to improve strength, range of motion, and movement mechanics.



### 3.4.2 Growth Disturbance and Deformity

- The widening of the physis is usually temporary and the attendant epiphyseal and metaphyseal blood supplies are essentially undisturbed.
- However, there may be an associated stress-related injury of the epiphysis which may further compromise blood supply to the physis and, in extreme cases, lead to growth irregularities in the physis.
  - Laor et al. Physeal widening in the knee due to stress injury in child athletes. Am J Roentgenol 2006.



Dempewolf et al. Youth kicker's knee: lateral distal femoral hemiphyseal arrest secondary to chronic repetitive microtrauma. *JAAOS Glob Res Rev* 2019;3:e079

### 3.1.2 Growth disturbance and deformity

	No. patients with growth disturbance	Sports and activities represented
Shoulder	3	Baseball (2), gymnastics (1)
Elbow	8	Baseball ( 4), gymnastics (4)
Wrist	21	Gymnastics (21)
Hand/fingers	11	Rock climbing (10), piano (1)
Knee	8	Basketball (3), rugby (1), soccer (3), tennis (1)
Ankle/foot	2	Ballet (1), flamenco dance (1)
	53	

### Shoulder

- Stress-related premature closure and angle varus deformity of the right proximal humeral physis in a 15-year-old male, elite level gymnast
  - Ejnisman B, Andreoli V, Pochini ADC, et al.. Proximal humeral epiphysiolysis in a gymnast a Ortop Bras. 2007; 15(5):290-291.



X-ray image of the proximal region of right humerus evidencing physeal plate enlargement



X-ray image of the proximal region of left humerus evidencing a normal physeal plate



X-ray image of the proximal region of right humerus with a 2-degree deformity in varus



X-ray image of the proximal region of left humerus with normal axial angle measurement



### Wrist

Fourteen-year-old female gymnast with chronic right wrist pain.

wrist pain. • **A**, Asymptomatic left wrist.

• **A**, Symptomatic right wrist showing partial closure of the right distal radial physis. The ulnar physis remains open.

Caine et al. A three-year epidemiological study of injuries affecting young female gymnasts. *Phys Therap Sport* 2003.



### Fingers

A 15-year-old climber with chronic pain in the proximal interphalangeal joint of his middle finger.

4A, x-ray and 4B, magnetic resonance image of an old and maligned proximal interphalangeal growth plate fracture of the middle finger.
4C, A picture of the hand showing swelling and deformity of proximal

interphalangeal joint of the middle finger. Images provided by Dr. Volker Schöffl, Germany



### Knee

- 11 <sup>1</sup>/<sub>2</sub> year-old girl who plays competitive tennis.
- Radiographs show physeal widening of both medial distal femoral physes and both medial proximal tibial physes
  - Laor et al. Am. J. Roentgenol. Physeal widening in the knee due to stress injury in child athletes. Am J Roentgenol 2006


Two years later, during which time the girl continued to play tennis intensely. There is relative varus alignment of both knees



Laor, T. et al. Am. J. Roentgenol. Physeal widening in the knee due to stress injury in child athletes. *Am J Roentgenol* 2006;186:1260-1264



Frontal radiographs of same girl taken at 11.5 years and at 17.5 years showing development of relative varus alignment of her lower extremities



Taken one month before x-rays showing physeal stress changes.



Taken 6 years after initial x-rays. She was non-compliant and continued vigorous tennis training



#### Feet

 Radiographs and MRI of the right foot revealed a shortened second metatarsal and growth plate closure of the head of the second metatarsal of the right foot

• Shah S. Premature growth plate closure in a ballet dancer en Pointe. *Clin J Sport Med* 2017.



A and B, Anterior-posterior and oblique view radiographs showing closure of second metatarsal head growth plate and shortened metatarsal.

#### Feet

- Premature growth plate arrest of the second metatarsal head physis in a 13-year-old ballet dancer from dancing *en pointe* 
  - Shah S. Premature growth plate closure in a ballet dancer *en Pointe*. *Clin J Sport Med* 2017



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#### 3.4.3 Surgery

• Of the 473 patients treated for PPSIs, 31 patients (6.6%) underwent surgery for their injury

Injury location	No. Patients	No. Surgaries
Shoulder	197	1 (>1%)
Elbow	47	11 (23.4%)
Wrist	98	9 (9.2%)
Hand/ fingers	80	2 (2.5%)
Knee	26	7 (26.9%)
Ankle/ foot	25	1(4%)
Total	473	31 (6.6%)

## 3.4.3 Surgery

- PPSI in a 15-year-old rugby player who had been intensely practicing his skills
- Secondary varus deformity of the femur was corrected with varus wedge opening osteotomy of the distal femur
  - Nanni et al. Stress-induced Salter-Harris I growth plate injury of the proximal tibia: first report. *Skeletal Radiol* 2005.





#### 3.4.3 Long-term health outcome

• PPSIs can counter the beneficial effects of sports participation at a young age if the child or adolescent is unable to continue to participate as a result of the residual effects of injury

# The Risk of OVERUSE Injuries

#### OVERUSE IN JURIES CAN BE

training errors, improper technique, excessive sports training, inadequate rest, muscle weakness and imbalances and early specialization.

#### LONG-TERM CONSEQUENCES INCLUDE

loss of playing time, reduced function and psychological exhaustion.

#### SYMPTOMS OF OVERUSE INJURIES

tend to be gradual, resulting in athletes going undiagnosed and untreated for longer periods of time.

#### OVERUSE INJURIES ARE general stress, inflammation and tendinitis.

COMMON

TO THE GROWTH PLATE CAN RESULT

from repeated microtrauma, which is microtearing of the muscle fibers and connective tissues.

#### STRESS FRACTURES

occur when shock that can't be absorbed from fatigued muscles is transferred to the bone.

#### WOMEN'S SPORTS, INCLUDING



HAVE THE MOST OVERUSE INJURIES

Rowing • baseball • volleyball • cross-country • track and field • other low-contact sports



Acute overuse injuries occur when there is too much activity, too quickly, while chronico veruse injuries result from repetitive activities over the course of several weeks or months.

#### 3.4.4. Long-term Health Outcome

- Although not consistently reported, timely return to the sport following PPSI injury and treatment appears common with sufficient rest
- There are, however, reports of patients who were encouraged to take up another position in their sport, at least temporarily, and to give up their sport altogether





Fig. 1—15-year-7-month-old boy who is football place kicker.
A, Frontal radiograph of right knee shows broad band of physeal widening of lateral aspect of distal femoral physis (*arrow*).
B, MRI shows broad area of lateral physeal widening of distal femur
C, Frontal radiograph obtained <u>3 months</u> after immobilization of knee shows near complete resolution of physeal widening.

### 3.4.4 Long-term Health Outcome

• In one study of LLS, treatment recommendations included rest in 99% of cases, physical therapy in 79% (including 100% of patients with GIRD), and position change upon return to play in 26%. Average time to full resolution of symptoms was 2.6 months, while average time to return to competition was 4.2 months.

• Heyworth et al. Trends in the Presentation, Management, and Outcomes of Little League Shoulder. Am J Sports Med 2016.



LLS of the right shoulder. Physeal widening of the (A) right proximal humerus as compared with the (B) left proximal humerus is clearly visible (arrows).

## 3.3.4 Long-term Health Outcome

 A concern related to PPSIs is that acquired length discrepancy, angular deformity, or altered joint biomechanics may cause long-term disability.

Loss of joint space

- Specifically, OA may result from chondral damage at the time of growth plate injury, articular incongruity or joint malalignment.
  - Maffulli et al. Long-term health outcomes of youth sports injuries. *Brit J Sports Med*. 2010

Prevalence of radiographic knee osteoarthritis in population compared to those with a history of knee injury. The Young Patient with the Old Knee!



**Roos E. Joint injury causes knee osteoarthritis in young adults.** Current Opinion in Rheumatology 2005; 17(2):195-200.

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Source: Mandelbaum et al. *Am J Sports Med* 1989

#### 3.4.3 Long-term Health Outcome

- In their 11-year follow-up of the German Junior National Climbing Team (1999-2011), there were signs of early stage osteoarthritis (defined by a Kellgren-Lawrence grade ≥2) in 6 climbers
  - Schoffl et al. Long-term radiographic adaptations to the stress of highlevel and recreational rock climbing in former adolescent athletes: An 11year prospective study. *Orthop J Sports Med* 2018.



#### 3.4.3 Long-term Health Outcome

- Limited longitudinal research involving elite-level gymnasts and rock climbers attests to the potential for early onset OA to develop secondary to PPSIs in young athletes.
- However, the incidence of this is largely unknown.
  - Caine D, Golightly YM. Osteoarthritis as an outcome of pediatric sport: an epidemiological perspective. Brit J Sports Med 2011.



What will they have longer, their trophies or their injuries?



 Young athletes engaged in a variety of sports, especially at advanced levels, may sustain PPSIs involving the shoulder, elbow, hand and wrist, knee, ankle and foot.



• There is some evidence which indicates that PPSIs are becoming more common; however, epidemiological studies are needed to investigate this possibility.

## KIDS AND SPORTS INJURIES

Are children and teens at greater risk today?



 Most PPSIs respond well to rest and timely treatment; however, in extreme cases some PPSIs may progress to skeletal growth disruption and deformity





- Rigorous longitudinal epidemiological studies of young athletes are needed to provide information on the incidence and outcome of PPSIs
- Noticeably lacking in the published work studies reporting prevalence and incidence rates for lower extremity PPSIs



• In the absence of large-scale coherent research one cannot help but wonder how many PPSIs go unrecognized.





# **Questions?**