Mechanic-dependent, high volume, high intensity overload throwing produces humeral osseous adaptation with concomitant epiphyseal stability in a youth baseball pitcher: a case study.

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Abstract

Numerous sources state or infer that high volume baseball pitching and throwing predisposes youth baseball players to a spectrum of “overuse” injuries. Rates of elbow and shoulder injuries among professional baseball pitchers are high, and cases of similar injuries are increasing among youth players. Epiphyseal damage, osteochondritis dissecans, tendon or ligament tears and ruptures, and other arm injuries among youth baseball players are well documented. Limiting the number of pitches thrown (i.e. ‘pitch counts’) has increasingly become the suggested method for minimizing likelihood of injury.

Current throwing-specific training regimens for baseball pitchers are unique when compared with training regimens for other athletic endeavors. Implicit assumptions are made that micro-damage is done with every high intensity pitch or throw, and suggested recovery times are significant. Hence, pitching workouts often emphasize low volume, low intensity workouts interspersed with infrequent high intensity sessions.

Current evaluation and teaching techniques compare the mechanics of youth players to adult contemporaries. Literature points to specific stresses capable of rupturing or tearing tissue, intimating that specific loading patterns have implications for joint injury. If current mechanical techniques are responsible for injuries, perpetuating the technique will continue to result in injury. Further, existing studies focus on recording current pitching techniques and analyzing resultant forces as opposed to pursuing an experimental approach that might lead toward mitigating potentially damaging stresses.

This case study demonstrates the effects on bone health of high volume throwing incorporating an experimental pitching mechanics model and experimentally developed training protocols. The techniques differ from current pitching techniques by combining baseball pitching skills with elite javelin-throwing techniques and proprietary findings. The training protocols incorporate high frequency, high intensity, overload training.

Based on the case study results it is hypothesized that limiting the number of pitches thrown will not significantly reduce the frequency and severity of pitching injuries. Instead, it is proposed that altering pitching mechanics to change the stresses or timing of loading patterns while maximizing training values will yield the desired results.

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Keywords: Overuse Injury, Biomechanics, Baseball Pitching, Pitch Counts, Pitching Mechanics, Osseous Adaptation, Overload Training

The frequency of injuries associated with pitching and throwing, at all levels of baseball, are of significant interest. "Injuries are at epidemic proportions among baseball pitchers, with nearly every adult pitcher sustaining a serious elbow or shoulder injury at some point in his career."[4] Injuries to youth baseball pitchers are also rising and represent a source of significant interest and concern for parents, coaches, researchers, clinicians and other health providers.[214] Discovering solutions for preventing or mitigating these injuries is vital for injury rates to decrease.

It is known that Major League Baseball (MLB) teams implement pitch counts as a technique for potentially limiting pitching injuries. Only recently has MLB begun statistical analysis of injuries reflective of time on the disabled list.[218] There is a statistical rise in the frequency of injuries among MLB players, most prominently among pitchers. Although pitch counts are used by MLB teams there are no concrete guidelines issued or adhered to system-wide.

Pitch counts have increasingly become the suggested method for preventing or limiting youth pitching injuries. Many recommendations were located that stress the importance of limiting volume of repetitions (pitch counts) or time of participation.[5,6,46,70,71,167,255 et al] Example recommended guidelines of limitations and suggested rest intervals are detailed by the USA Baseball Medical & Safety Committee (American Sports Medicine Institute position statement).[252] It is not known if these guidelines have been strictly adhered to or if they have yielded a reduction in the frequency and/or severity of youth pitching injuries; however, if pitch counts contributed significantly toward reducing pitching/throwing injuries, we should see injury rates declining. Instead they appear to be increasing.[5, 214]

The 2011 National Athletic Trainers' Association position paper states that "although little research has identified causative factors for overuse injuries in children and adolescents, these injuries may be caused by training errors, improper technique, excessive sports training, inadequate rest, muscle weakness and imbalances, and early specialization."[255] Of the preceding criterion, current best practice points to overuse (i.e. number of repetitions, combined with insufficient rest) as the most significant contributor of pitching injuries. There is a preponderance of literature pointing toward limiting the number of actions as the means of cure. Although current position statements link mechanical proficiency and overuse there are no guidelines detailing best mechanical or technique practices, especially technique that can readily be assessed under field conditions.[255]

Baseball pitching involves the entire body: initiated by gross motor movements it culminates in fine motor skills as the ball is released. Describing what happens at the physical level requires a broad base of descriptors spanning many disciplines: biomechanics and kinetics, high speed imagery analysis, motor learning and motor control, neurology, applied anatomy & physiology, athletic training, nutrition and, of course, baseball coaching and instruction. The broad knowledge base required, added to the neuromuscular complexity of the activity, intimates the difficulty of assessing simultaneously multiple body systems through a continuum of body movements that culminate in among the fastest recorded actions produced by the human body.[78] Because of this complexity, transferring knowledge gained in the laboratory or clinical setting for practical use by on-field coaches and instructors is challenging.

Many studies have been located that detail efforts to scientifically document the baseball pitching motion.[1,6,13,28,58,64,72,77,78 et al] Current technique for assessing pitching mechanics compares an individual to an 'average' database (or individual elite player) as opposed to an idealized mechanical model. Existing visual models illustrate pitching by dividing mechanical sequences into 'phases.'[6,102,201,263 et al] However, quantifying and assessing an individual's baseball pitching mechanics is more complex than comparing his delivery to averages or another player, because no two pitchers execute their delivery in exactly the same way. Not only do mechanics differ from individual to individual (whether quantified by biomechanics assessment or comparative kinematic analysis), but there are potential differences in individual anatomy that may have impact on mechanics.[108]

A literature search located many studies that hint at mechanical causes for associated injuries, although little is known about specific injury mechanisms.[102,255, et al] It is known that forces produced during pitching generates stresses sufficient to disrupt healthy tissue with every pitch.[41,188] Studies with adult pitchers have documented these stresses and current models have attempted to correlate stresses with injury potential. However, no studies have been located that examine cumulative damage caused, one pitch at a time.

One study was located that makes specific recommendations referencing benchmarks that might lead to more 'efficient' mechanics, although no correlation is made between efficiencies and the longterm health of subjects referenced as efficient.[103] Further, the suggested definition of 'efficient pitching mechanics' addresses relative efficiencies on the basis of velocity only and does not address pitch location, ball movement, sequencing of pitches, or statistical effectiveness of pitchers sampled. No studies were located that suggest mechanical technique alterations that might limit elbow or shoulder injuries, and no studies were located that make sophisticated analysis available in a form that coaches can adopt as anatomically sound teaching protocols. No studies have been located that detail an experimental process that attempts to alter these stresses, especially in relation to joints at particular points in time (sequencing). An 'ideal' technique for baseball pitching mechanics has not been described in previous scientific literature, especially one that correlates theoretically correct anatomical movement and sequencing.

Although the literature search located studies that address interval training programs specific to throwing protocols, none of these studies detail acquisition of specific mechanical skills in conjunction with interval progressions or strength training.

It is hypothesized that, in the case of baseball pitching, the dominant factor in current rates of pitching injuries correlates strongly with improper technique. It is theorized that an experimental approach to pitching mechanics can yield technique that is anatomically sound, promoting tissue, joint and bone health, instead of yielding injuries. The entire scope of this suggested methodology is beyond the purview of a single paper, yet this theory is the guiding principle behind the paper.

It is hypothesized that specific loading patterns and the timing of these patterns can contribute to anatomically sound or unsound stress. This paper presents an adolescent case study where the mechanical model and teaching protocol designed to implement the model has resulted in beneficial bony adaptation without yielding elbow growth plate damage. Based on limited experimental evidence obtained it is postulated that the solution to pitching arm injuries lies more in mechanical solutions and sufficient training protocols as compared to limiting the number of actions (i.e. pitch counts).

It is hypothesized that developing an 'ideal' model based on criterion from many disciplines can provide coaches and instructors with practical knowledge from the lab and clinic. It is further proposed that implementing an ideal model, with teaching protocols that lead subjects to conform to the model, will yield declining injury rates. This paper presents a model for evaluating and visually assessing the baseball pitching motion based on theoretically correct anatomical sequencing and timing of movements.

It should be noted that an experimental approach does not consist of a neat, tidy package that is easily described. Experiments, including technique used in development of the model and subsequent teaching protocols, have undergone many revisions and these alterations are not detailed herein. Undoubtedly there will be future revisions as additional discoveries are made and suggestions incorporated.

Thus, the greater aim of this paper is, within the confines of evidence produced, to suggest a systematic, encompassing, interdisciplinary, experimental approach to solving or reducing baseball's arm injury problems.

Methods & Materials

Research Design:

1. Experimentally develop a mechanics/biomechanics model that conforms to theorized anatomically correct criterion.
2. Develop teaching & training protocols that implement the model.
3. Compare results of the teaching protocol against biomechanics model, make corrections/alterations, repeat.
4. Case Study & Assessment: Evaluate x-rays for positive or negative results.

Each of the four elements in the study design are detailed in following sections.

Development of the Mechanics/Biomechanics Model:

Overarching theory behind development of the model: if we can learn to throw heavy weighted implements with technique that is anatomically sound (i.e. does not produce damage), and if this technique can be reproduced at high rates of speed with a baseball, we are likely to discover ideal technique. The technique presented in the model was developed with maximal effort applied to weighted implements ranging from 0.15kg (5.25 ounce standard weight baseball) to 13.61kg (30 pounds). Beginning in late 2007, this technique was developed through three years of trial and error testing. The subject used in development of the biomechanics model was a former professional pitching prospect. Subject's visual kinematics and techniques, recorded at 1000 frames-per-second, closely match with implements ranging from 0.15kg (5.25 ounce) baseball to 0.45kg (1#), 0.91kg (2#), 1.36kg (3#) and 4.5kg (10#) weighted balls. A bibliography of many resources accessed in design and development of the model is located in Appendix 2.[1-279]

Throwing overweight (and underweight) baseballs has been studied and reported on.[66,67,85] Data from two of these studies strongly support increases in throwing velocity. It was noted that no injuries were reported during these studies, but no broader injury data is available and should be the focus of additional study.[85]

Studies that detail overload/underload training suggest maximum overloads and underloads of about 20%. For a 0.15kg (5.25 ounce) baseball this would indicate maximum implement weights of about 6.3 ounces. Unpublished Russian studies dating to the 1970's indicate that if overloads greater than 20% are imposed, the biomechanics are altered such that training is no longer specific. During experimental development of the model presented in this paper the subject was able to reliably reproduce visual kinematics (recorded at 1000 fps) with weighted implements up to 10 pounds. It seems possible that, for baseball pitching and throwing, overloads in excess of 20% may prove beneficial. However, for the heaviest weights used during design of the model, it seems questionable if a point of diminishing returns is reached in ballistic training value.

Data acquired from the subject's performance during development of the model derives the following table:

Ballistic Energy Calculations:

Ball Wt. (Kg)	Ball Wt. (lbs)	V (km/hr)	V (mph)	V (fps)	ME (joules)	ME (ft-lbs)
4.54	10	46.67	29	42.53	376.10	277.40
1.36	3	93.34	58	85.07	458.00	337.80
0.45	1	125.53	78	114.4	274.01	202.10
0.15 - Baseball	0.328	140.01	87	127.6	120.52	88.89

Based on standard ballistic energy calculations, it was determined that somewhere between a 0.45kg (one pound) ball and 4.54kg (ten pound) ball maximum ballistic training value is likely achieved. Muzzle energy of the projectile (ME) was hypothesized to equate with energy expended by the subject. One study was located that correlated significantly higher risk of longterm degenerative changes associated with throwing of objects in excess of 3kg (6.6 lbs).[231] It was elected to cap maximum overload training weight at 1.36 kg (three pounds), and periodized decline training progressions were designed and accomplished with 1.36kg (3lb.), 0.90kg (2lb.), and 0.45kg (1lb.) weighted balls.

The technique goals listed below appear to work together, in concert, to produce the results attained. Based on experimental testing it was noted that if one component is significantly altered the technique seems to fail, both theoretically and practically.

General technique goals hypothesized to conform to anatomically correct criterion:

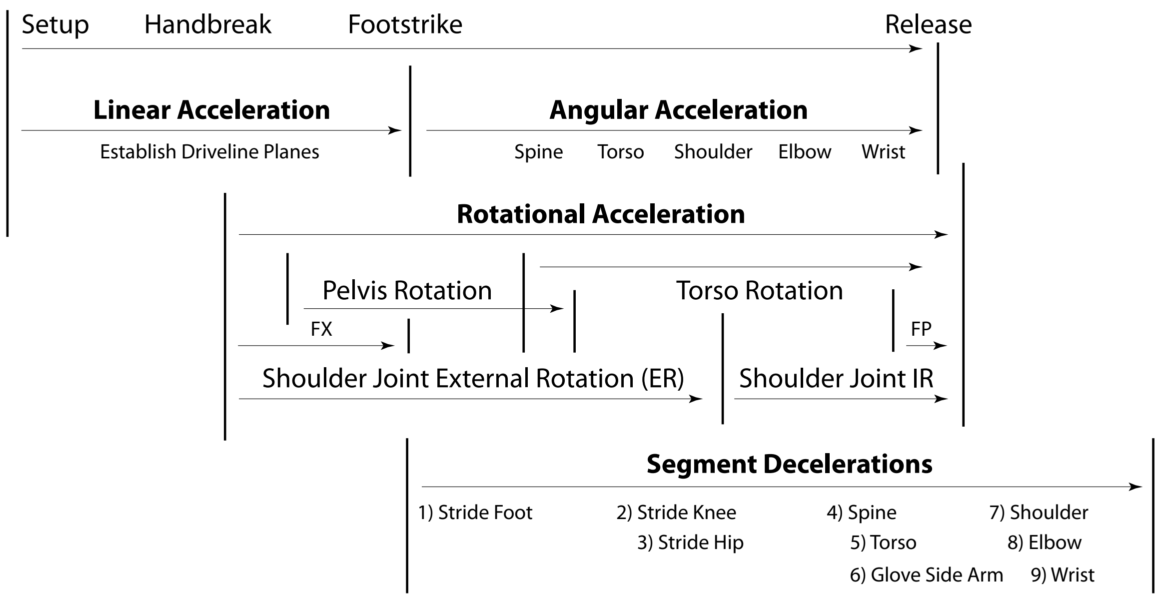
- Achieve a driveline that exhibits minimal lateral and vertical ball displacement once the subject braces the stride (front) leg.
- Exhibit bracing of the stride leg without hyperextension of the stride knee.
- Produce uninterrupted ball acceleration once the ball is in the driveline (exhibits a loading pattern where the ball does not accelerate simultaneously backward and downward while the hips and torso rotate forward).
- Produce a loading pattern where significant upper arm external rotation is achieved at footstrike (avoiding slamming into external rotation through many degrees range of motion at high rates of speed).
- Maintain bilateral glenohumeral alignment from footstrike through deceleration (avoiding significant shoulder horizontal hyperabduction).
- Produce uninterrupted forward rotational movement of the hips and torso until segment decelerations occur.
- Produce uninterrupted downward and rearward glove arm movements to assist angular/rotational movements of the torso.
- Produce angulation of the torso and shoulder line (avoiding significant lateral displacement of the ball while simultaneously attaining minimal vertical displacement).
- Produce forearm acceleration and deceleration patterns that avoid elbow hyperextension.
- Produce sequential segment decelerations (as segments slow down it may provide evidence that energy is transferred; the shorter the time span of deceleration the more efficiently energy is transferred).
- Produce throwing arm followthrough decelerations in direct alignment with plane of ball flight.

Mechanics/Biomechanical Model Description:

The model was compiled from imagery taken from two sequential baseball pitches (front/overhead view and side view), recorded at 1000 frames-per-second using a Phantom high speed camera. Average release velocity of these two pitches was 86.7 mph, determined by independent analysis from time/distance calculations using Xitex motion analysis software.[232] It is noted that release velocities of the model subject place him in the elite range for pitchers sampled in a lab/clinical setting.[4] (Note: the subject is left-handed, and for purposes of comparative analysis some imagery has been flipped horizontally.) The model displays a sequential progression of timing elements hypothesized as critical, but does not reflect relative time frames. As acceleration rates increase time frames become compressed.

RPM Pitching® Linear / Angular / Rotational Constant Acceleration Model

Developed in collaboration with John D'Acquisto



Notes:

- Driveline Planes are the vertical (sagital) and horizontal (transverse) planes established by position of the ball when it arrives 'up in back' at footstrike as shown in the corresponding side-view image above.
- Handbreak, forearm extension (FX), initial shoulder joint external rotation, and lifting upper arms to driveline are actions that establish the Driveline Planes; all are controlled actions.

- Shoulder joint and elbow joint decelerations occur together in sequence from proximal to distal: long axis rotation concept. [Insert ref]
- In order to transfer maximum energy to subsequent segments, it is theorized the preceding segment must decelerate.
- Applying angular movement to a rotational movement may result in a more linear movement.
- Daily training with weighted implements (wrist weights, weighted baseballs) and baseballs generally exceeded 250 repetitions per day, a minimum of six days per week.

The model as proposed produces the following kinematics:

Figure 1. Minimal lateral displacement.

Figure 2. Minimal horizontal displacement (anterior wrist tracking).

Figure 3. Uninterrupted horizontal acceleration of the baseball.

Teaching Methodology & Training Protocols: Implementing the Mechanical Model

Based on early successes derived during design of the mechanical model (extended, daily, high volume throwing with heavy implements and baseballs, without injury; increasing pitch velocities) it was deemed advisable to expand trials to youth athletes. It must be stressed that developing the teaching methodology and training protocols was accomplished through trial and error. This approach yielded valuable information about what to do (and what not to do), and efficient ways for accommodating individual differences. Resources utilized included consultations with PhD's (areas of specialization in motor learning and biomechanics) and athletic trainers/coaches who have trained Olympic and professional athletes.

Studies have demonstrated the advisability and potential benefits of strength training for young athletes.[90] Specific strength training for young athletes has been shown to offer significant gains in muscular fitness, yet there are great unknowns regarding training volumes and intensity recommended for baseball pitching. Because little is known about suggested volumes, the teaching methodology and training protocols were produced experimentally based on self-reported assessment of training discomfort. Discomfort was assessed on an ongoing basis to minimize potential risk.

Two phases of training were designed to run concurrently: general fitness and activity-specific fitness. As implemented, the general fitness program emphasized ambidexterity, coordination, flexibility, endurance and strength. There is increasing evidence that ambidexterity training promotes motor development and athletic capacity, and a variety of exercises stressing bilateral crossover were adopted.[22,24,41,83,84,91, et al] General fitness and bilateral motor development were addressed together in training. Assessment tools used to establish levels of general fitness included knee and hip stability during body-weight squats as a measure of leg and core strength. As a general concept, flexibility was equated with mobility through a complete normal range of joint motion.[238] Also as a general concept, as flexibility increased it was deemed vital to have sufficient strength to support the full range of motion. Numerous body-weight exercises were utilized in making individual adjustments for bilateral strength, along with agility drills to promote lateral movement. As the subject gained strength and fitness, and became more mature (judged on the basis of puberty and/or skeletal maturation), training protocols were intensified. Activity-specific goals and program design are outlined below.

Training goals hypothesized to conform to anatomically correct criterion and motor learning training principles:

- Bilateral symmetry of training protocols. (Encourage bilateral motor development and build equal strength from top to bottom, left to right, and front to back)
- Drill sets emphasize backward chaining and athletic specificity.
- Strive to perfect upper body movements first then progress to adding lower body skills.
- Periodized overload progressions incorporate flexibility & mobility, strength and power training phases, and recovery.
- One rest day per week provides recovery from specialized training.
- Off-season progressions of training intensity, load, intervals and distance provide time for meaningful strength training and physiologic adaptation. The program was designed to provide simulated game intensities at competitive distances with realistic numbers of pitches thrown in competition.
- In-season maintenance levels of general and specific fitness training provide added training during competitive seasons.
- Daily training frequency: 3 days per week maximal intensity; 3 days per week technique development; one day per week rest. Daily throwing training is accomplished in roughly one hour per day, including time for instruction.

Implements used for pitching-specific training:

- Standard-weight implements (0.15kg (5.25 ounce) baseball)
- Overload-weight implements (2.27kg (5 pound) and 4.54kg (10 pound) wrist weights, 0.34kg (12 ounce) and 0.45kg (16 ounce) weighted balls).

After assessing the subject's relative levels of fatigue and discomfort, typical workouts began with two wrist weight exercises: pronated swings and shakedowns.[173] The shakedown exercise has been modified from the original design to promote bilateral movement. Both wrist weight resistance exercises are intended to promote blood flow, mobility, and joint lubrication, exercising the arms and shoulder girdle through full ranges of humeral internal and external rotation coupled with forearm pronation.

Once wrist weight exercises were finished, two dynamic shoulder mobility exercises were completed and the subject then begins the training protocol for the day. In alignment with the overarching goal of learning to deliver the baseball with mechanics identical to those used with a heavy weighted implement, initial training sessions focused on use of wrist weights and weighted balls. Once sufficient technique and strength were acquired the training focus shifted to maximal effort overload repetitions and transferring the technique to baseballs. It was discovered that alternating weighted ball overload repetitions with baseball repetitions assisted in speeding transfer of over-weight technique to baseball technique.

Initial focus with baseball training was on fastball delivery, then breaking pitches (curveball, slider, sinker) were introduced. The training progression used in the case study is detailed below. Routine assessments to evaluate how the subject conformed to the model were made utilizing 120 and 240 frames-per-second high speed imagery obtained using a Casio EX-FH100 camera. A variety of drills were designed and utilized to assist the teaching protocols.

Case Study:

The case subject is a right-handed 13 year old male competitive baseball player. At the close of his 2011 fall baseball season, bilateral x-rays of the elbows (humeral mid-shaft to distal phlanges; AP and lateral views) were performed to determine advisability of continuing current training regimens. In addition to general impressions, specific areas of interest included the medial epicondyle growth plates and humeral cortical thickness. In the three previous years, 2009-2011, the subject has been part of ongoing experiments that examine the results from and advisability of high volume, high intensity overload throwing and conditioning workouts. The experimental mechanical model has been detailed above. Other elements of the study were self-reported by the case subject using a journal format (Table 1).

Concurrent with baseball pitching training the subject also participated in generalized fitness programs designed to increase overall strength and conditioning, with focuses on speed, agility, and dexterity. The subject participates in no other organized sports besides baseball. The subject was throwing 4-seam fastballs, cut fastballs, curveballs, and was learning the slider and sinker. All pitches are thrown with an intentionally pronated/inwardly rotated release.

During the 2011 fall and summer competitive seasons the subject recorded the following: Innings Pitched: 48 1/3; Pitch Count: 867; Average Pitches/Inning: 17.95.

Table 1.
Training Regimen: (commencing 11/8/2010)

Week	WW PS (6X)	WW Shakedown (6X)	WW Throws (3X/wk)	Wt.	Wtd ball (3X)	Baseball (alt)	PCount (est)	
1	24 5#	24 5#	12 5# Wrong foot				48	
2	24	24	24 5#				48	
3	24	24	36 5#				60	
4	24	24	48 5#				60	
5	24	24	48				60	
6	36	36	48				72	
7	36	36	48				72	
8	36	36	48				72	
9	48	48	48				84	
10	48	48	48				84	
11	48	48	48				84	
12	36	36	36				96	
13	36	36	(2X per week begins)				108	
14	36	36					108	
15	36	36					120	
16	36	36					120	
17	36	36		12 oz.	16	16	72	
18	36	36			16	16	72	
19	36	36			16	16	84	
20	36	36			16	16	84	
21	36	36			16	16	96	
22	36	36			24	24	96	
23	24	24	24		24	24	96	Games begin
24	24	24	24		24	24	96	
25	24	24	16		16	16	96	
26	24	24	16		16	16	96	
27	24	24	16		16	16	96	
28	24	24	16		16	16	96	
29	24	24	16		16	16	96	
30	24	24	16		16	16	96	
31	24	24	16		16	16	96	
32	24	24	16		16	16	96	
33	24	24	16		16	16	96	
34	24	24	16		16	16	96	
35	8 reps 10#	8	8	16 oz.	12	12	96	
36	8	8	8		12	12	96	
37	8	8	8		12	12	96	
38	8	8	8		24	24	96	
39	8	8	8		24	24	96	
40	8	8	8		24	24	96	
41	12 reps 10#	12	12		24	24	96	
42	12	12	12		24	24	96	
43	12	12	12		36	36	96	
44	12	12	12		36	36	96	
45	12	12	12 (square drill)		36	36	96	
46	12	12	12		36	36	96	
47	12	12	12		36	36	96	
48	12	12	12		36	36	96	
49	12	12	12		36	36	96	
50	12	12	12		36	36	96	
51	12	12	12		36	36	96	
52	12	12	12		36	36	96	
					828	828	3840	
		2-Nov-11			828x2=1656	828x2=1656	840x3 (wks 1-12)	
		Physical Exam - Xrays					3864x2 (wks 13-52)	

1656	Wtd Ball Reps
1656	Alt. Bball
2520	Wks 1-12 Training
7728	Wks 13-52 Training
13560	Training Total
867	Game Pitches
14427	Total

Assessments and Results:

1. Radiology report
2. Comparative kinematics
   - Construct and visually assess lateral and horizontal displacement overlays; compare against the mechanical model.
   - Construct and visually assess horizontal acceleration graphs (manually digitized); compare against the mechanical model.

Radiology Report (Independent analysis was submitted by the subject's orthopedic doctor: radiographs were reviewed and interpreted by a radiologist blinded to the study objectives.)

At the time x-ray films were performed and reviewed the subject had no structural pain or discomfort. In the previous twelve months the subject self-reported temporary discomfort from throwing or pitching in the right medial triceps, right latissimus dorsi, and left-side obliques. At no time during or after training did the subject utilize ice or NSAIDS to treat training fatigue or discomfort.

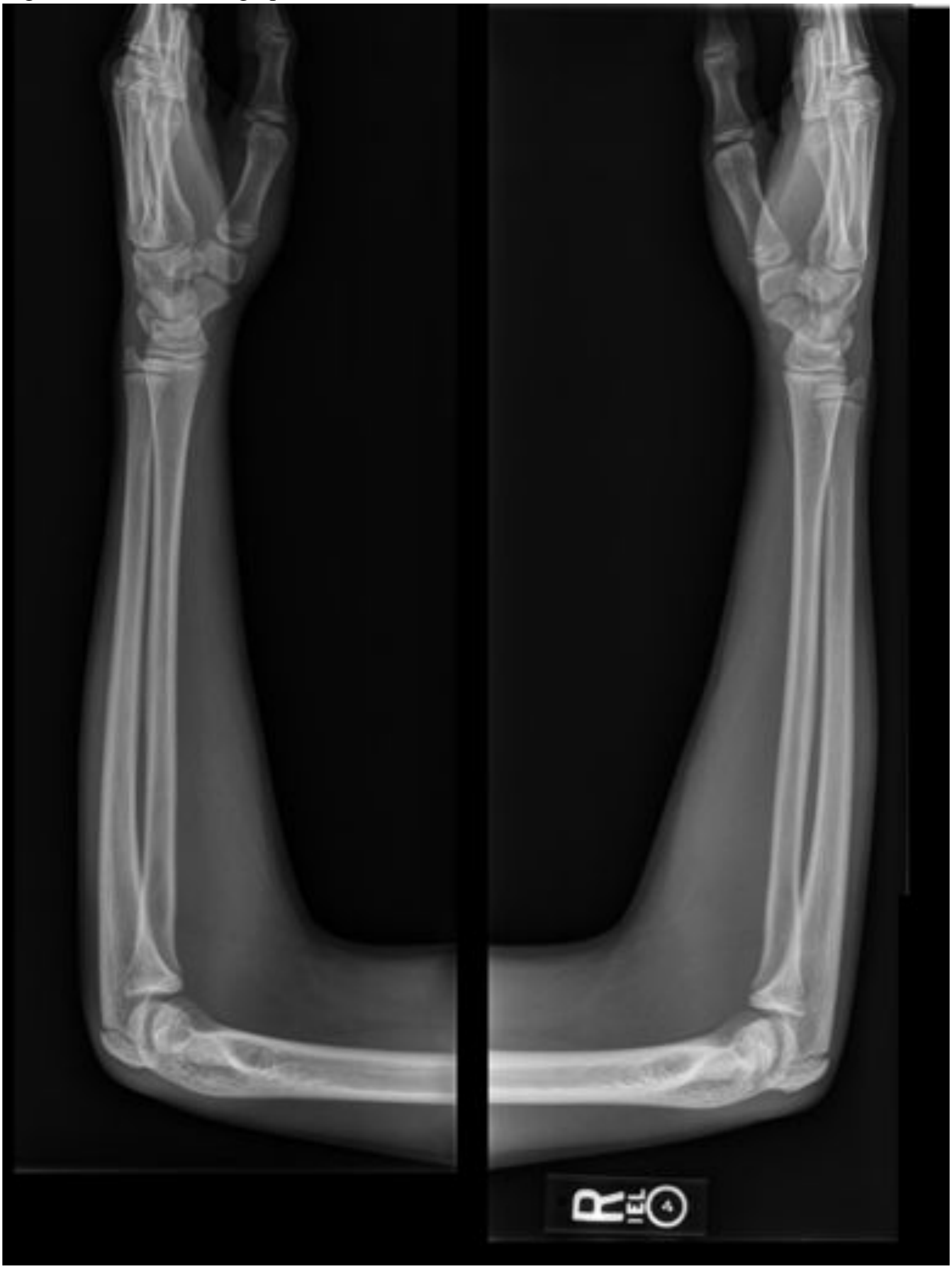
EXAM: TP XR FOREARM BILAT
ORD DIAG: ASSES GROWTH PLATES

FINDINGS: Bilateral forearms were performed. There is no fracture or acute bony abnormality. The growth plates appear well maintained and in good alignment. The unfused apophyses of the medial epicondyle are visualized bilaterally. There is no acute bony abnormality. The right medial epicondyle is slightly more advanced in development than the left. There is no soft tissue calcification. There are no opaque foreign bodies. No joint effusion.

IMPRESSION: NO FRACTURE OR ACUTE BONY ABNORMALITY. THE MEDIAL EPICONDYLES OF THE ELBOW DEMONSTRATE NO ACUTE CHANGES. THE RIGHT MEDIAL EPICONDYLE IS SLIGHTLY MORE ADVANCED IN DEVELOPMENT AND OSSIFICATION THAN THE LEFT. THIS MAY BE RELATED TO ASYMMETRIC USE.

Figure 4. Anterior/Posterior Radiographs.

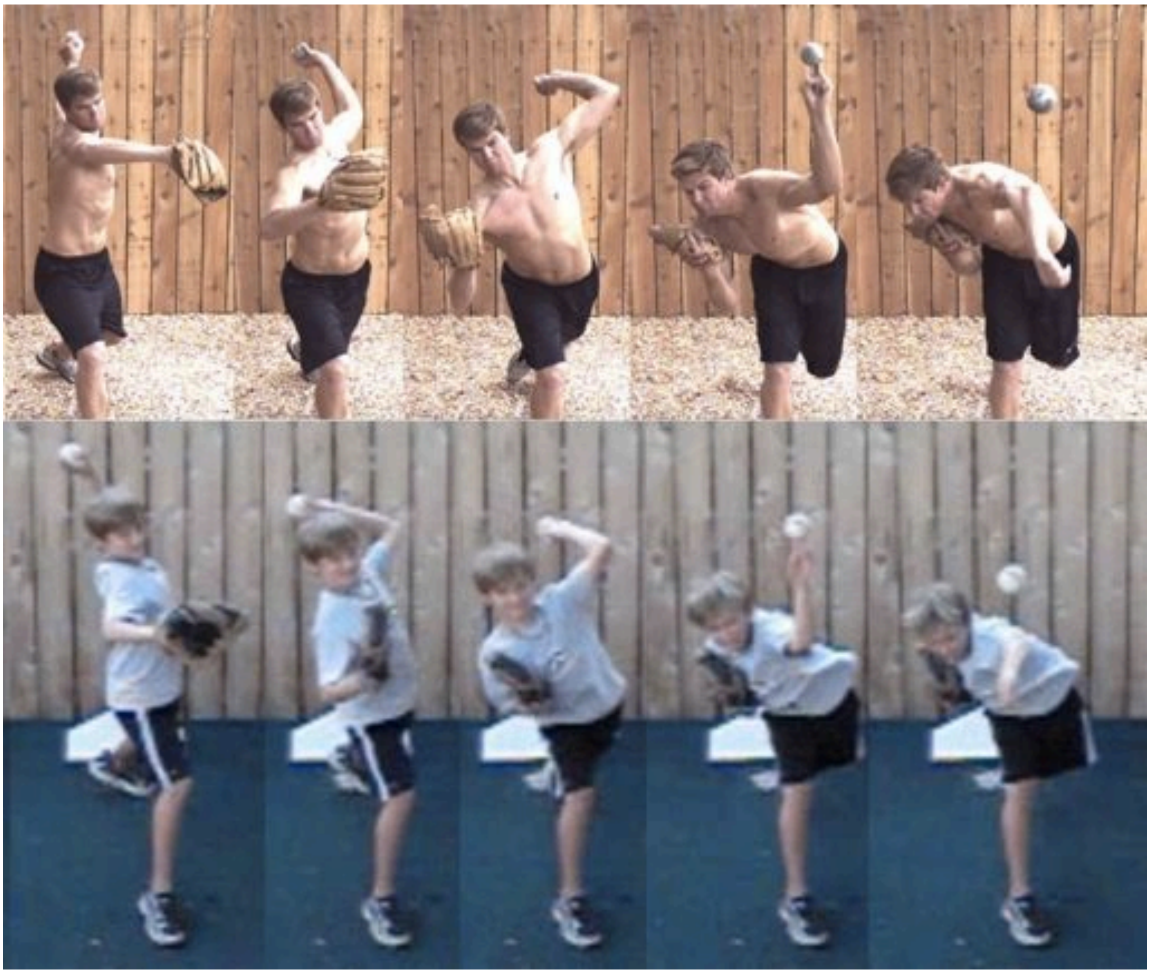
Figure 5. Lateral Radiographs.



Visually, it is noted that there is significant difference in humeral cortical thickness.

Comparative Kinematics:
Does the case study subject's visual kinematics conform to the biomechanical model?

Figure 6. Visual comparison of Front View Kinematics.



Observations:
- Bilateral glenohumeral alignment is maintained throughout acceleration and deceleration, and is visualized in both subjects.
- At ball release, vertical forearm orientation with elbow flexion is visualized in both subjects.
- Immediate followthrough of the throwing arm and hand is in relative alignment with the driveline plane.

Figure 7. Visual comparison of Side View Kinematics.

Observations:

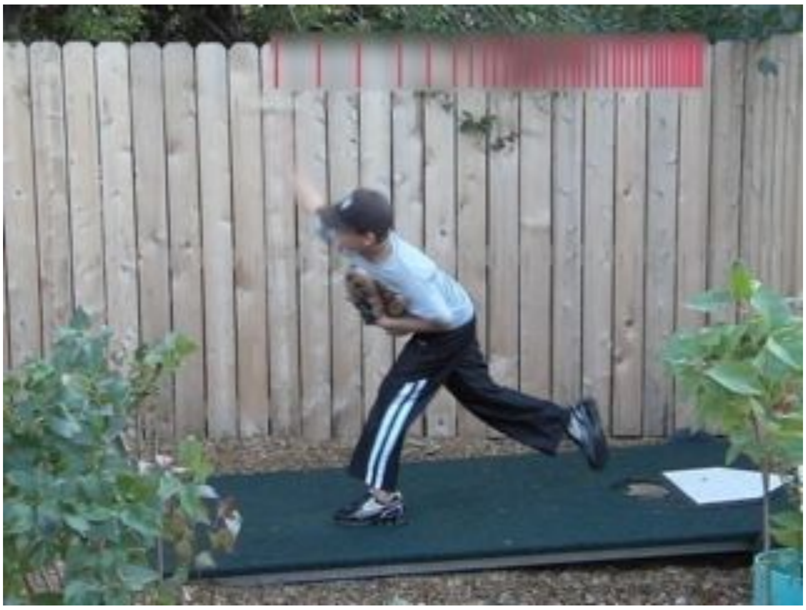
- Bilaterally, the elbows in the case study subject collapse slightly and torso angulation is not fully achieved. In spite of this inefficiency the adolescent subject is observed to achieve minimal lateral displacement (see Fig. 8), and is observed to exhibit the same ball acceleration pattern as the model subject (see Fig. 9).

Figure 8. Visual comparison of lateral ball displacement.

Observations:

- Minimal lateral displacement of the ball is visualized in both subjects.
- The model subject is pitching from flat ground while the adolescent subject is throwing from an angled mound surface. Combined with inexact camera placement and differing heights of the subjects, this contributes to the effect of the ball appearing lower in the frame.

Figure 9. Visual comparison of horizontal acceleration graphs.



Constant horizontal acceleration of the ball is visualized in both subjects.

Discussion and Conclusions:

In spite of maximal effort, high volume, overloaded throwing, the adolescent case study subject exhibits no remarkable symptoms of degenerative disease or injury in the elbow. Throughout twelve months of extended training the subject was asymptomatic for joint or connective tissue discomfort. Results of the case study suggest that utilizing a biomechanics model that emphasizes anatomically correct sequencing and timing provides opportunity to maximize training and conditioning, with minimal rest intervals, while maintaining health of tissues and structures.

If the model and training protocols can prove their efficacy in extended trials it may be possible to substantiate unsound vs sound anatomical movements in the baseball pitching motion using this methodology. The mechanical model and training protocols will benefit from continued refinements made by additional study and experimentation.

Visual comparison of humeral cortical thickness revealed significant bilateral differences. The subject's throwing arm humerus exhibits substantially thicker cortex as compared to the non-throwing arm, which serves as the control. It seems likely that this increase is a result of physiological adaptation in response to bending stress from overload training stressors. It is suggested that assessing bilateral humeral cortical thickness can potentially provide clues about anatomical soundness of ballistic athletic movements like baseball pitching. Though this study focused on conclusions we can draw from radiographs, it is possible to make inferences about related soft tissue. During his training the subject experienced no remarkable discomfort in soft tissues around the elbow or shoulder, only in the belly of muscles. It is inferred adaptive tendon and ligament strength has increased commensurate with osseous adaptation.

The young man in the case study pitched and threw almost daily…on the order of 14,500 pitches…in the previous calendar year. Approximately one-third of these pitches were accomplished at full intensity with a 0.34kg (twelve ounce) or .45kg (one pound) weighted ball. The subject was also a catcher and shortstop on his team. These criterion, including limited rest and recovery times, significantly exceed suggested guidelines currently published. While the competitive innings thrown were within guidelines suggested by the USA Baseball Medical & Safety Committee, the sheer volume of pitches thrown (with and without heavy training implements) raises questions about the viability of pitch counts and pitch limits. It is acknowledged that a variety of baseball pitching injuries are caused by repetitive motion. However, the case study calls into question if these injuries should properly be termed 'overuse injuries' if the movements and sequences that cause them are inherently, anatomically unsound.

Based on evidence collected during design of the mechanical model, it is suggested that weighted balls in excess of three pounds are unnecessary for training purposes, and may in fact reduce velocity potential of elite subjects. Trials are underway with the case study subject to determine efficacy of adolescent training with 0.91kg (two pound) overweight balls. (Note: At the completion of his overload training phase the case subject participated in continued overload training and an underload component was added to the protocol. The underload component of the training is not addressed in this paper.)

While one suggested goal of training pitchers is to gain sufficient skill and fitness such that they become capable of pitching an entire baseball game, especially at later ages, monitoring these workloads must be done on an individual basis based on athletic fitness and mechanical soundness. It is suggested that pitching coaches and instructors gain meaningful training in a broad base of subjects, including athletic training, applied anatomy, and physical therapy. It is also suggested that pitching coaches and instructors routinely assess mechanics using high-speed imagery, documenting evaluations of structural pain and/or muscular discomfort. Few coaches have routine access to sophisticated biomechanics facilities. Although this study presents a model that was constructed from 1000 frames-per-second imagery, the case study provides crossover to 120 and 240 frames-per-second technology that is available to consumers at relatively low cost. For comparative purposes, using hypothetically key timing points in a youth pitcher's delivery, it appears that 240fps imagery can supply most of the information needed for evaluating injury potential and for enhancing mechanics…especially if a workable comparison model exists.

*Footnote: Baseball coaches and instructors are certain to ask how well the youth case study subject competed. The subject's competitive team won their league championship and he was the winning pitcher in the championship game. An additional group of youth pitchers who have been trained, at least partially, in the manner described, won back-to-back state championships in 2010-11, posting a cumulative team earned run average of 3.28, and were rated as highly as fourth in the USSSA national rankings. Another young man, similarly trained, won an 18U Connie Mack state championship game in 2012, posting a summer-long record of 12W-1L. Of this grouping there were no arm injuries, no playing time lost to arm trouble, and no sore arms.

Case Study Limitations:
Radiological conclusions were made from a single x-ray set (noting that these films were taken at the close of a year's competition without time for significant rest or healing). In the absence of 'before' x-ray films, the control consists of the subjects' non-throwing arm. The table presented with the case study is an accurate portrayal of the protocol used, however there were days the subject did more (or less) work than represented, based on coaching guidance. Although the study was not designed to provide significant statistical analysis, differing frame rates of cameras, relatively unsophisticated equipment utilized, lack of overhead views and inexact camera placement all impact the ability to provide exacting data.

Future Recommendations: A broader base study is currently underway to examine a larger sample size of youth pitchers. To incrementally increase mechanical efficiencies of subjects it would be useful to assess rotational velocities of the pelvis, trunk, and upper arm in combination with visual assessment of high speed imagery. Inferential studies that test relationships between the kinetics and kinematics of experimentally derived mechanics would be useful. Detailed comparative analysis of matched groups of subjects would also be useful in examining humeral cortical adaptations. It is suggested that glenohumeral stability and proximal humeral growth plates are assessed along with elbow growth plates. 'Before' and 'after' X-ray films may provide additional documentation about rates of adaptation in cortical thickness, and detailed statistical analysis of the cortical adaptations would be useful. It is suggested that adopting a comprehensive and systematic method for evaluating mechanics and corresponding injuries would be beneficial, especially one that can be easily understood and put into practice by coaches and instructors.

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Appendix 1

"ASMI Position Statement for Youth Baseball Pitchers"
Updated March 2011

"With the rise in elbow and shoulder injuries is youth baseball pitchers, the adult community needs to take steps to prevent these injuries. Research points to overuse as the principle risk factor. Poor pitching mechanics also contribute to injury risk. Another suggested risk factor is poor physical fitness.

Throwing curveballs has been suggested as a risk factor, but the existing research does not support this concern. However, a youth pitcher may not have enough physical development, neuromuscular control, and proper coaching instruction to throw a curveball with good mechanics. Throwing curveballs too early may be counter-productive, leading to arm fatigue as well as limiting the youth's ability to master fastball mechanics.

Thus, the recommendations for preventing injuries in youth baseball pitchers are:

- *Watch and respond to signs of fatigue. If a youth pitcher complains of fatigue or looks fatigued, let him rest from pitching and other throwing.*
- *No overhead throwing of any kind for at least 2-3 months per year (4 months is preferred). No competitive baseball pitching for at least 4 months per year.*
- *Do not pitch more than 100 innings in games in any calendar year.*
- *Follow limits for pitch counts and days rest. (Example limits are shown in the table below.)*
- *Avoid pitching on multiple teams with overlapping seasons.*
- *Learn good throwing mechanics as soon as possible. The first steps should be to learn, in order: 1) basic throwing, 2) fastball pitching, 3) change-up pitching.*
- *Avoid using radar guns.*
- *A pitcher should not also be a catcher for his team. The pitcher-catcher combination results in many throws and may increase the risk of injury.*
- *If a pitcher complains of pain in his elbow or shoulder, get an evaluation from a sports medicine physician.*
- *Inspire youth pitchers to have fun playing baseball and other sports. Participation and enjoyment of various physical activities will increase the youth's athleticism and interest in sports."*

Example limits for number of pitches thrown in games

Age (yrs)	2006 USA Baseball Guidelines	2010 Little League Baseball Regulations
Daily limits		
17-18	n/a	105/day
15-16	n/a	95/day
13-14	75/game	
11-12	75/game	85/day
9-10	50/game	75/day
7-8	n/a	50/day
Weekly limits		
13-14	125/wk; 1000/season; 3000/yr	
11-12	100/wk; 1000/season; 3000/yr	
9-10	75/wk; 1000/season; 2000/yr	
7-18		21-35 pitches --> 1 day rest; 36-50 pitches --> 2 days rest; 51-65 pitches --> 3 days rest 66- pitches --> 4 days rest

*It is noted that the above guidelines account only for pitches thrown in competition and do not account for pitches thrown in training.

Table 7. Suggested Sport-Modification Recommendations for Adolescent Pitchers
1. Avoid pitching with arm fatigue.
2. Avoid pitching with arm pain.
3. Avoid pitching too much. Future research needed, but the following general limits are:
    a. Avoid pitching more than 80 pitches per game.
    b. Avoid competitive pitching more than 8 months of the year.
    c. Avoid pitching more than 2500 pitches in competition per year.
4. Pitchers with the following characteristics should be monitored closely for injury
    a. Those who regularly use anti-inflammatories to "prevent" injuries
    b. Regularly starting pitchers
    c. Pitchers who throw < 85 mph (137 kph)
    d. Taller and heavier pitchers
    e. Pitchers who warm up excessively
    f. Pitchers who participate in showcases

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