Shoulder adaptive changes in youth baseball players

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*Shoulder adaptive changes in response to overhand throwing have been observed in adults, but the age of onset and progression of these adaptive changes have not been established. Two-hundred ninety-eight youth baseball players (8- to 28-year-olds) were studied to determine whether shoulder range of motion and laxity differences between the dominant and non-dominant shoulders exist between different age groups. The subjects were separated into 3 different age groups of 100 8- to 12-year-olds (Group 1), 100 13- to-14 year-olds (Group 2), and 98 15- to 28-year-olds (Group 3). For dominant shoulder external rotation with the humerus in abduction, all groups were significantly different from each other, with Group 2 having the greatest range and Group 1 having the smallest range (*P $<$ *.05). When comparing dominant shoulder internal rotation in abduction among different groups, Group 3 and Group 2 motion was significantly less than that for Group 1 (*P $<$ *.05.) When comparing dominant to non-dominant shoulder motion within each group, a significant increase in dominant shoulder external rotation in abduction was found in all 3 age groups (*P $<$ *.05). Comparison of the differences in external rotation in abduction between the dominant and non-dominant shoulders demonstrated an increase with increasing age, Group 1 (1.5 ± 6.8°), Group 2 (9.6 ± 15.3°), and Group 3 (15.0 ± 11.2°;* P $<$ *.05). Comparison of differences in internal rotation in abduction between dominant and non-dominant shoulders demonstrated a decrease with increasing age, Group 1 (4.6 ± 8.2°), Group 2 (8.4 ± 14.5°), and Group 3 (15.5 ± 11.7°;* P $<$ *.05). For shoulder laxity, Groups 2 and 3 had significantly more inferior shoulder laxity when compared to Group 1. In summary, our results indicate that shoulder range of motion and laxity of youth baseball players are caused by adaptive changes that manifest during adolescence. (J Shoulder Elbow Surg 2006;15:562-566.)*

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Tremendous forces are generated about the shoulder during overhand throwing, with elite baseball pitchers generating peak humeral internal rotation torques up to 111 N-m.[9,26] These huge repetitive forces challenge the involved bone and soft tissues, and place the shoulder at risk for injury. Shoulder soft tissue and bone adaptations in response to these huge forces have been observed in several studies.[3,8,10,11,16,22,23] Specific changes include anterior capsular stretching, posterior capsular tightening, and increased humeral and glenoid retroversion.[3,8,10,11,16,23] These changes result in clinically measurable increased external rotation and decreased internal rotation of the dominant shoulder compared with the non-dominant shoulder.[3,8,10,11,16,23]

Developing injury prevention strategies related to overhand throwing in skeletally immature athletes has gained recent interest.[17] It is now believed that many pitching injuries treated at higher levels of competition result from cumulative microtrauma that begins at the youth level.[2] Although adaptive changes to the shoulder from throwing have been well studied in mature athletes, the age of onset and progression of these adaptive changes have not been established. The objective of this study was to measure adaptive shoulder changes in throwing athletes of different age groups to determine the time period during skeletal growth when these changes occur.

MATERIALS AND METHODS

Two hundred ninety-eight baseball players from 3 different age groups were examined. The athletes were baseball players in the New Jersey Amateur Athletic Union (AAU), South Shore Little League, and South Shore Babe Ruth League of Staten Island, NY. All subjects completed a questionnaire to identify any potentially confounding variables, such as previous shoulder pathology or shoulder surgery. Two subjects were excluded from the study population because of previous shoulder surgery that limited their shoulder range of motion. The different age groups consisted of 100 8- to 12-year-olds (Group 1), 100 13- to 14-year-olds (Group 2), and 98 15- to 28-year-old athletes

Table I Subject demographics

Group	Mean	Range
Group 1 (8–12 y.o.) (N = 100)		
Age (years)	10.32	8–12
Years playing organized baseball	4.64	1–8
Height (inches)	55.12	48–67
Weight (lbs.)	83.77	55–220
Group 2 (13–14 y.o.) (N = 100)		
Age (y)	13.54	13–14
Years playing organized baseball	7.55	3–10
Height (inches)	65.70	56–74
Weight (lbs.)	129.33	70–225
Group 3 (15–28 y.o) (N = 98)		
Age (years)	18.07	15–28
Years playing organized baseball	12.02	5–18
Height (inches)	70.02	64–77
Weight (lbs.)	173.03	120–260

y, years; y.o., years old.

(Group 3). The age groups were chosen to categorize subjects based on their skeletal growth. The youngest group represents skeletal immaturity, the middle group represents skeletal immaturity during the time period of maximal growth, and the oldest group represents subjects approaching and reaching skeletal maturity. For each group, the average age, average number of years playing organized baseball, average height, and an average weight are presented in Table I. In Group 1, there were 10 (10%) left-hand dominant players and 90 (90%) right-hand dominant players. In Group 2, there were 11 (11%) left-hand dominant players and 89 (89%) right-hand dominant players. In Group 3, there were 18 (18.37%) left-hand dominant players and 80 (81.63%) right-hand dominant players. For these age groups, most players play multiple positions including pitching, infield, outfield, and catching. There were no isolated hitters.

Physical examinations were performed during the play-off and all-star tournament seasons after the athletes had played approximately 30 regular season games. All physical examinations were conducted during the same week, after all the subjects had completed the third month of their 4-month baseball season. All physical exams were performed by 2 senior level orthopedic surgery residents under the direct supervision of an attending orthopedic surgeon fellowship trained in sports medicine and shoulder surgery. The subjects were randomly assigned to each examiner. All subjects had warmed up with short tossing prior to being examined. Passive glenohumeral range of motion was assessed using a large goniometer.[13] The following measurements were obtained: forward elevation in the scapular plane (FE), external rotation with the humerus at the side (ER-side), external rotation with the humerus in 90° of abduction (ER-abd), and internal rotation with the humerus in 90° of abduction (IR-abd). Measurements were recorded with the subject lying supine to stabilize the scapula. Active internal rotation was then measured from a seated position as the highest vertebral level reached (IR-vert). This vertebral level was then converted to a numerical value as determined by the American Shoulder and Elbow Surgeons' scale.

Inferior shoulder laxity was assessed in all subjects for both dominant and non-dominant shoulders by the presence of an inferior sulcus sign and graded on a numerical scale of 0-3+: Grade 0: 0 mm inferior translation of the humeral head, grade 1+: <5 mm translation, grade 2+: 5-10 mm translation, and grade 3+: >10 mm translation. Anterior shoulder laxity was calculated using the load-and-shift test, and graded on a scale of 0-3+: Grade 0: no displacement of the humeral head; grade 1+: displacement to the rim of the glenoid fossa, but not perched on the rim; grade 2+: displacement until humeral head is perched on the rim of the glenoid fossa; and grade 3+: perched and locked dislocation. Generalized ligamentous laxity was evaluated by assessing ability to passively position thumb to radius, metacarpal-phalangeal joint hyperextension, and elbow recurvatum, which were performed for both dominant and non-dominant extremities.

The data were then analyzed using a 2-way analysis of variance (ANOVA) with age group as 1 factor and hand dominance as the second, repeated factor. Student-Newman-Keuls multiple comparisons tests were used to locate differences between groups, if a difference was found by the ANOVA. The effect of hand dominance within groups was analyzed using a 1-way, repeated-measures ANOVA for each group. A 1-way ANOVA with a Student-Newman-Keuls multiple comparisons test was used to determine if the difference in the range of motion in internal and external rotation between the dominant and non-dominant shoulders was statistically different between groups. A value of statistical significance was set at $<.05$.

RESULTS

Range of motion

Between age groups. The overall range-of-motion results for each age group from the 2-way ANOVA are summarized in Table II. Forward elevation for Group 1 was statistically less than either Group 2 or Group 3. For ER-side, Group 2 was significantly greater than Group 3, which was statistically greater than Group 1. For ER-abd, all groups were significantly different from each other, with Group 2 having the greatest external rotation and Group 1 having the smallest. For IR-abd, the range of motion for Group 3 and Group 2 was significantly greater than that for Group 1. For IR-vert, Groups 1 and 2 were found to be significantly larger than Group 3. Therefore, except for IR-vert, the ranges of motion were found to be greater for the older age groups than for the youngest age group.

Within age groups. The results on the effect of dominance on the range of motion within age groups from the 1-way repeated ANOVA are also shown in Table II. A + indicates the only conditions where there is no statistical difference between the dominant and non-dominant shoulder within a group. For Group 1, there was no difference in forward elevation and ER-side, whereas ER-abd was greater for the dominant shoulder and IR-abd and IR-vert were less for the dominant shoulder. For Group 2, forward elevation,

Table II Dominant and nondominant shoulder range of motion measurements in degrees

	FE (SD)*	ER-side† (SD)	ER-abd† (SD)	IR-vert† (SD)	IR-abd (SD)*
Group 1					
Dominant	173 (8.6)‡	43 (8.9)‡	96 (5.9)	17.7 (1.6)	33 (9.1)
Non-	173 (9.0)	42 (8.5)‡	94 (7.2)	18.6 (1.4)	37 (9.1)
Group 2					
Dominant	182 (7.8)	53 (15.6)	115 (19.5)	17.2 (2.3)	40 (10.0)
Non-	181 (7.8)	49 (14.4)	105 (12.7)	18.6 (1.8)	49 (13.8)
Group 3					
Dominant	181 (6.2)	49 (13.3)	109 (12.1)	15.8 (2.3)	38 (9.5)
Non-	180 (6.2)	43 (13.8)	94 (6.9)	17.9 (1.9)	54 (12.3)

FE, forward elevation; ER-side, external rotation in 0° of abduction; ER-abd, external rotation in 90° of abduction; IR-vert, internal rotation in 0° of abduction; IR-abd, internal rotation in 90° of abduction.

*Group 1 is statistically different from Groups 2 and 3 ($P < .05$).

†Groups 1, 2, and 3 are all statistically different from each other ($P < .05$).

‡Indicates the only cases within a group where the dominant and nondominant shoulders are *not* statistically different ($P < .05$).

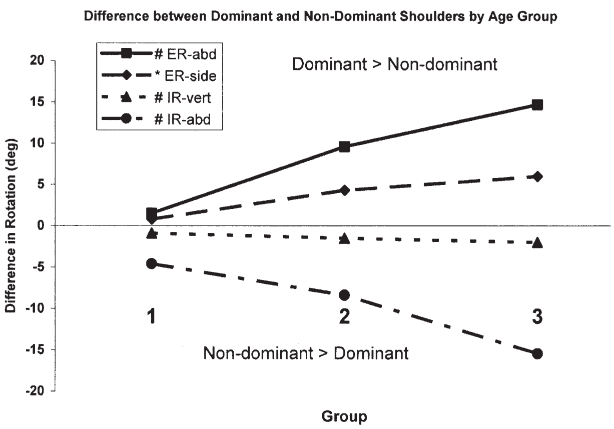

Figure 1 Graph of the differences between the dominant and non-dominant shoulders for external rotation with the humerus in 90° abduction (ER-abd), external rotation with the humerus at the side (ER-side), active internal rotation while seated reaching to the highest vertebral level (IR-vert), and internal rotation with the humerus in 90° abduction (IR-abd), as a function of age group. *Group 1 statistically different from Groups 2 and 3, which are not different ($P < .05$). #Groups 1, 2, and 3 are all statistically different ($P < .05$).

ER-side, and ER-abd were greater for the dominant shoulder, whereas IR-abd and IR-vert were less for the dominant shoulder. Finally, for Group 3, forward elevation, ER-side, and ER-abd were greater for the dominant shoulder, whereas IR-abd and IR-vert were less for the dominant shoulder.

Difference between dominant and non-dominant side by age group. Figure 1 shows the results of the 1-way ANOVA comparing differences between the dominant and non-dominant shoulder for internal and external rotations as a function of age group. The differences in ER-abd show a clear increase with increasing age group, with the differences in Group 1 (1.5 ± 6.8°), Group 2 (9.6 ± 15.3°), and Group 3 (15.0 ± 11.2°) are all statistically different. The differences in ER-side show the same trend, with Group 2 (4.3 ± 11.6°) and Group 3 (6.1 ± 10.8°) statistically different from Group 1 (0.8 ± 5.2°), but the difference between Groups 2 and 3, although increasing, is not statistically different. Conversely, for IR-abd, the negative difference increases between Group 1 (−4.6 ± 8.2°), Group 2 (−8.4 ± 14.5°), and Group 3 (−15.5 ± 11.7°) are all statistically different. The same applies to IR-vert, with the increasing differences between Group 1(−0.9 ± 1.2°), Group 2 (−1.5 ± 2.0°), and Group 3 (−2.0 ± 1.9°) all statistically different.

Laxity measurements

Average sulcus sign measurements in the dominant shoulder for Groups 1, 2, and 3 were; 0.94 ± 24, 1.20 ± 45, and 1.25 ± 48, respectively. Average sulcus sign measurements in the non-dominant shoulder for Groups 1, 2, and 3 were: 0.94 ± 24, 1.22 ± 46, and 1.25 ± 48, respectively. For both dominant and non-dominant shoulders, Groups 2 and 3 had significantly more inferior shoulder laxity when compared to Group 1.

Average humeral head displacement on load-and-shift testing in the dominant shoulder of Groups 1, 2, and 3 were: 1.06 ± 24, 1.38 ± 51, and 1.28 ± 49, respectively. Average humeral head displacement on load-and-shift testing in the non-dominant shoulder of Groups 1, 2, and 3 were: 1.06 ± 24, 1.36 ± 50, and 1.29 ± 49, respectively. For both dominant and non-dominant shoulders, Groups 2 and 3 had significantly more dominant anterior shoulder laxity compared to Group 1.

Group 1 had significantly more generalized ligamentous laxity than did Groups 2 or 3. Group 1 averaged 1.32 ± 0.84 positive tests used for determining generalized ligamentous laxity (thumb flexion to forearm, metacarpal-phalangeal hyperextension, and elbow recurvatum). Group 2 averaged 0.78 ± 0.89 positive tests for ligamentous laxity. Group 3 averaged 0.83 ± 0.95 positive tests. The difference in generalized ligamentous laxity observed between Groups 2 and 3 did not reach significance.

DISCUSSION

Several investigators have suggested that the side-to-side differences in shoulder range of motion and laxity observed in overhead athletes are the result of adaptive changes to the soft tissue and bone structures of the shoulder, but have not determined when these adaptive changes occur.[4,8,13,19–22,25] We have observed significant dominant-non-dominant differences in shoulder range of motion of baseball players that occur during adolescence while skeletally immature. These results suggest that the side-to-side difference in shoulder range of motion of baseball players result from adaptive influences during bone growth and soft tissue growth.

Crocket et al[8] described the specific bone adaptations of increased humeral head retroversion that leads to measured increased external rotation and decreased internal rotation. Humeral head retroversion may be capable of change during growth in skeletally immature athletes.[15] The proximal humeral physis undergoes rapid growth from age 13 to 16, which may be the time window when these bony changes occur. This is consistent with our results that show increased external rotation and decreased internal rotation after age 12 (Figure 1).

Adaptation of bone to external stress has been demonstrated in many studies,[12,14,15] and is consistent with Wolff's Law.[27] In a mathematical model of throwing, the subscapularis has been estimated to produce a maximum force of 1030 N during internal rotation.[7] Peak internal rotation torque of 111 Nm occurs at maximal external rotation as the pitcher transitions from the cocking phase to the acceleration phase.[26] During this transition, the ball momentum continues to rotate the humerus externally, stretching the subscapularis, while the subscapularis begins to contract to initiate internal rotation and forward acceleration, creating a huge eccentric contraction. Reflecting the increased stresses throwing places on the shoulder in young athletes, Lyman et al.[17] have demonstrated that curveballs, the number of pitches thrown during a game, and the number of pitches thrown during a season are all significant risk factors for shoulder pain in young pitchers.

Little Leaguer's Shoulder is a proximal humeral epiphyseal overuse syndrome, often considered a stress fracture of the epiphyseal plate.[1,5,6,24] These patients present near the age of 14 with gradual onset of pain while throwing. Radiography reveals a widening of the physeal plate on the anteroposterior views in internal and external rotation.[6] It is believed that Little Leaguer's Shoulder is related to the frequency and intensity of pitching.[6] Although this is a symptomatic overuse condition, it suggests that the proximal humerus adapts and responds to the repeated stresses it experiences.

The bony adaptation of increased glenohumeral retroversion observed by Crockett[8] allows for more external rotation before the shoulder is constrained by the anterior capsule and glenohumeral ligaments. Increased external rotation creates a larger arc of motion used to generate angular velocity prior to ball release during throwing. Crocket et al[8] postulated that baseball players adapt an increase in humeral head retroversion in their dominant shoulder to reach an elite level and with less risk of injury. In addition they noted that there may be a window of opportunity for this adaptation to occur before growth stops.

Mair et al[18] correlated shoulder pain with range-of-motion differences and radiographic changes in the dominant shoulder of skeletally immature throwers. The proximal humeral physeal width was significantly greater on the dominant side for the entire group, in subjects with symptoms during the current season, and in subjects without symptoms. Radiographic changes were found in subjects with pain (62%), as well as in those subjects without symptoms (55%). Subjects had increased external rotation of the dominant arm compared with the non-dominant arm. The authors postulated that increased external rotation in the young thrower is a result of changes in the bony architecture. Although their study population numbered 78, their range of motion results are consistent with our study population of 298. Furthermore, we measured an increasing loss of internal rotation with older age group (Figure 1), which may be the result of adaptive changes in the throwing shoulder initiating with increased external rotation, and followed by the development of posterior capsular contracture and decreased internal rotation. The adaptive changes in humeral rotation also coincided with adaptive changes in increased sulcus sign and glenohumeral translation testing for the older age group compared to the younger age groups.

Several limitations of our study must be considered. Interobserver and intraobserver variability with clinical examination of range of motion and grading in translation testing may have existed. However, each player was examined by an individual examiner such that side-to-side differences were controlled for. Another limitation of this study is the lack of radiographic studies to quantify the exact bony changes that take place. Although these data would have added to the study, these data has been quantified previously by Crocket et al.[8] Furthermore, the goal of this study was to identify the onset of bony and soft tissue adaptations and whether these changes occur during skeletal immaturity. In addition, we wished to avoid the necessary radiation in these skeletally immature subjects to quantify bone adaptations. A more controlled study design would longitudinally evaluate throwing athletes during their skeletal growth. This type of study, however, requires an extensive time frame and subject follow-up.

Our results indicate that the side-to-side difference in shoulder range of motion of baseball players is present both within all 3 groups of athletes tested as well as across groups, and the progressive increase of these differences with increasing age appears to be the result of adaptive influences that has been suggested in previous studies. This study has demonstrated a significant dominant-non-dominant difference in shoulder range of motion of baseball players within age groups, as well as a significant difference that increases with increasing age.

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