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The Effect of the Crow Hop on Elbow Stress During an Interval Throwing Program

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Background: Postoperative rehabilitation protocols after ulnar collateral ligament (UCL) reconstruction typically involve a structured interval throwing program. In an effort to minimize torque placed on the UCL, athletes are often instructed to throw with a crow hop, even at short throwing distances. However, the effect of the crow hop on medial elbow stress is unknown.

Purpose/Hypothesis: The purpose was to determine whether elbow stress differs with and without a crow hop across the throwing distances of a typical interval throwing program. We hypothesized that crow hop throws would generate lower torque on the elbow than standing throws at each distance of the interval throwing program.

Study Design: Controlled laboratory study.

Methods: Healthy high school and collegiate pitchers and position players were recruited from the surrounding area. Each player was outfitted with a wearable athletic sleeve and device that recorded elbow torque (Newton-meters), arm slot (degrees), arm speed (revolutions per minute), and shoulder rotation (degrees). Ball velocity (miles per hour) was measured using a radar gun. Players were instructed to perform 3 crow hop throws and 3 standing throws at distances of 30, 45, 60, 90, 120, 150, and 180 feet. A repeated measures analysis of variance was used to compare ball velocity, elbow torque, arm slot, arm speed, and shoulder rotation between crow hop and standing throws at each throwing distance.

Results: Twenty athletes participated in this study (average age, 17.8 years; range, 15-25 years). The average medial elbow torque increased at each distance for both crow hop and standing throws at distances of 30, 45, 60, and 90 feet ($P < .05$), after which there were no significant increases in elbow torque ($P > .05$). The average torque was higher for crow hop throws than standing throws at distances of 30 feet (13.9 N·m vs 12.0 N·m; $P = .002$), 45 feet (21.8 N·m vs 19.3 N·m; $P = .005$), and 60 feet (28.0 N·m vs 24.5 N·m; $P = .02$).

Conclusion: Crow hop throws generated greater medial elbow torque than standing throws at distances up to 60 feet; however, there were no differences in elbow torque at distances greater than 60 feet between the 2 throw types. For both crow hop and standing throws, elbow stress increased at each distance interval up to 90 feet before plateauing at distances greater than 90 feet. The crow hop throwing technique does not reduce medial elbow stress during a simulated interval throwing program, and it may actually increase torque at shorter throwing distances.

Clinical Relevance: The results of our study indicate that it would be prudent for players to initially perform standing throws at shorter distances and only later be allowed to employ a natural crow hop at greater distances to minimize torque placed on the medial elbow during UCL rehabilitation protocols.

Keywords: baseball; crow hop; elbow stress; elbow torque; ulnar collateral ligament

The rate of ulnar collateral ligament (UCL) injuries continues to rise among overhead-throwing athletes, particularly baseball pitchers.[4,8,10,23] Surgical reconstruction is commonly performed to allow pitchers to return to competitive play.[2,13,15,22] A major component of rehabilitation protocols includes throwing at progressively greater distances over the span of several months. These interval throwing programs specify for a gradual, controlled increase in throwing distances to gradually increase the torque placed on the medial elbow. In an effort to further minimize torque placed on the UCL, athletes are often instructed to throw with a crow hop, even at short throwing distances. The crow hop is believed to promote recruitment of the core and lower body, which supplements the kinetic chain of the throwing motion, thus reducing the effort required from the upper extremity and protecting the medial elbow from undue stress.[6,28]

Postoperative protection of UCL reconstruction is critical to allow restoration of preinjury stability. Understanding the effect on elbow torque of variations within UCL reconstruction rehabilitation protocols is important for

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improving surgical outcomes. A previous study has suggested the crow hop to be protective against excessive valgus loads.[25] However, that study did not include the shorter throwing distances at the beginning of the interval progression when the reconstruction was at greatest risk. In addition, within that study, players were instructed to throw “hard, on a horizontal line.” Standard practice in the context of traditional UCL rehabilitation programs is to throw on an arc and with just enough effort to reach the intended target.[24] To date, there remains a gap in understanding regarding the influence of the crow hop on elbow torque and other pitching parameters in the context of a typical interval throwing program.

The purpose of this study was to determine whether elbow stress differs with and without a crow hop across the throwing distances of a typical interval throwing program. We hypothesized that crow hop throws would generate lower torque on the elbow than standing throws at each distance of the interval throwing program.

METHODS

This study was performed with institutional review board approval (No. 12377). High school and collegiate pitchers and position players were recruited from the surrounding area through direct contact with coaches and athletic trainers. Players were included in the study if they were actively participating in practice/competition, capable of throwing with 100% effort, and without self-reported injuries or limitation in throwing capabilities. Players were excluded if they were injured, recovering from injury, or otherwise not regularly participating with team activities. Before throwing, all participants completed an intake form that consisted of demographic information including age, hand dominance, injury history, and previous baseball experience.

Players were outfitted with an athletic sleeve (Motus Global) containing a sensor positioned 1.5 inches distal to the medial epicondyle of the humerus. Sleeve size was chosen by the player based on comfort. The sensor contained a triaxial gyroscope and a triaxial accelerometer used to compute 4 biomechanical parameters including medial elbow torque (Newton-meters), arm slot (degrees), arm speed (rotations per minute), and shoulder rotation (degrees). This sensor has been used in previous studies of baseball pitchers.[5,18,20,21] Although it has demonstrated high correlation with measurements obtained from high-speed motion capture (r = 0.93 for elbow torque), it has not yet been thoroughly validated in the orthopaedic literature.[5] The correct positioning of the sensor on each player was confirmed by the research team before throwing and periodically throughout the duration of the study. Participants were then advised to participate in any warm-ups that allowed them to perform to their highest ability. Warm-ups included stretching, jogging, and practice throws at the player’s discretion.

TABLE 1
Player Demographics

	Mean	SD	Range
Age, y	17.8	2.5	15.0-25.0
Height, m	1.8	0.06	1.7-2.0
Weight, kg	83.4	19.4	61.2-147.4

The pitchers then underwent a throwing protocol consisting of crow hop and non-crow hop throws at various distances. Cones were placed at distances of 30, 45, 60, 90, 120, 150, and 180 feet, which are common distances utilized in interval throwing programs. Participants threw 6 total throws at each distance, 3 with a crow hop and then 3 without a crow hop before moving to the next distance. The non–crow hop technique consisted of the player taking 1 step toward the target with his nondominant leg and then throwing the ball; no explicit instructions were given for crow hop technique. Similar to traditional UCL rehabilitation protocols, participants were instructed to throw on an arc, with just enough velocity to reach the target. Participants were given 30 to 60 seconds of rest between throws, a technique previously shown to minimize fatigue and prevent variation in throwing mechanics.[9] For each throw, the aforementioned biomechanical parameters were collected by the wearable sensor, and ball velocity (miles per hour) was collected by radar gun positioned behind the thrower (Stalker Sport II radar gun; Stalker).

Statistical Analysis

Player demographic data are described using means, standard deviations, and ranges. Pitch parameters are presented using least squares means and standard errors. A repeated measures analysis of variance (ANOVA) was used to compare ball velocity, elbow torque, arm slot, arm speed, and shoulder rotation between crow hop and standing throws at distances of 30, 45, 60, 90, 120, 150, and 180 feet. Throw type (crow hop or standing) was the independent variable; the 5 pitching parameters were the dependent variables. Models were run for each distance

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TABLE 2
Medial Elbow Torque at Each Throwing Distance[a]

	Distance (feet)						
	30	45	60	90	120	150	180
Crow hop average torque, N·m[b]	13.9 (0.4)	21.8 (0.6)	28.0 (0.9)	32.9 (1.0)	35.3 (1.1)	36.6 (1.2)	37.8 (1.3)
Standing throw average torque, N·m[b]	12.0 (0.4)	19.3 (0.6)	24.5 (0.9)	30.9 (1.0)	34.0 (1.1)	35.6 (1.2)	36.4 (1.3)
P value	**.005**	**.010**	**.016**	.182	.418	.559	.457

[a]Torque values presented as least squares means (SE). *P* values reflect comparisons between crow hop and standing throw at each distance. Bold values indicate $P < .05$.
[b]Indicates significant differences ($P < .05$) between 30 and 45 feet, 45 and 60 feet, and 60 and 90 feet. The initial repeated measures analysis of variance was $P < .001$ for each cohort.

TABLE 3
Other Biomechanical Parameters at Each Throwing Distance[a]

	Distance (feet)						
	30	45	60	90	120	150	180
Ball velocity, mph							
Crow hop	36.3	44.6	51.0	56.3	58.6	60.6	63.4
Standing	33.1	41.4	47.2	53.7	56.8	59.3	61.5
P value	**<.001**	**.003**	**.002**	**.020**	.131	.280	.089
Arm slot, deg							
Crow hop	64.4	59.9	53.1	50.7	49.3	45.8	45.2
Standing	64.3	59.6	54.9	50.9	47.9	45.6	44.4
P value	.960	.893	.469	.943	.508	.926	.729
Arm speed, rpm							
Crow hop	345.8	526.7	661.2	752.8	796.1	838.6	874.3
Standing	319.2	484.0	599.4	726.7	779.4	827.3	866.4
P value	.248	.140	**.048**	.330	.456	.551	.655
Shoulder rotation, deg							
Crow hop	137.2	146.0	150.0	155.2	160.8	166.3	170.9
Standing	134.3	143.0	148.8	153.7	160.4	165.6	168.2
P value	.302	.177	.487	.354	.829	.689	.140

[a]Values presented as least squares means. *P* values reflect comparison between crow hop and standing throw at each distance. Bold values indicate $P < .05$.

separately. A repeated measures ANOVA model was also used to compare sequential distance pairs (30-45, 45-60, 60-90, 90-120, 120-150, and 150-180 feet) for medial elbow torque. When comparing each sequential distance pair, a Benajmini-Hochberg adjustment was applied to the *P* value to control the type I error rate. Statistical significance was set at $P < .05$. All analyses were performed using SAS 9.4 (SAS Institute Inc) and SPSS 25.0 (IBM Corp).

RESULTS

Twenty high school and collegiate athletes participated in this study. The average age was 17.8 years (Table 1).

The average medial elbow torque increased at each distance for both crow hop throws and standing throws up to 90 feet ($P < .05$), after which there was no significant increase in elbow stress for either type of throw. Elbow torque for crow hop throws began at 13.9 N·m at 30 feet and increased to 37.8 N·m at 180 feet compared with elbow torque for standing throws, which began at 12.0 N·m and increased to 36.4 N·m for throws of 30 feet and 180 feet, respectively (Table 2).

The average torque was higher in the crow hop cohort at all distances compared with the average torque of the standing throw cohort (Table 2). These differences were statistically significant at distances of 30 feet (13.9 N·m vs 12.0 N·m; $P = .002$), 45 feet (21.8 N·m vs 19.3 N·m; $P = .005$), and 60 feet (28.0 N·m vs 24.5 N·m; $P = .02$). No statistically significant differences were seen between the 2 cohorts at distances greater than 60 feet.

Average ball velocity was also significantly greater for crow hop throws when compared with standing throws at distances of 30, 45, 60, and 90 feet (Table 3). There were no significant differences in arm speed, arm slot, or shoulder rotation at any distance between these 2 types of throws, with the exception of increased arm speed for crow hop throws at a distance of 60 feet (661.2 rpm vs 599.4 rpm; $P = .048$).

DISCUSSION

The results of this study showed that during an interval throwing program, medial elbow torque was higher in crow hop throws compared with standing throws at distances 60 feet and below, after which there was no difference. Our study found a statistically significant increase in elbow torque at each increasing distance up to 90 feet, at which point the elbow torque plateaued and only increased by 15% from 90 feet to 180 feet.

Previous studies that have evaluated elbow stress during an interval throwing program have demonstrated similar results. A study by Fleisig et al[11] used high-speed motion capture to evaluate 17 college pitchers and found a significant increase in elbow varus torque at each increasing throwing distance of 37 m (120 feet), 55 m (180 feet), and maximum distance throws. A study by Leafblad et al[17] evaluated 60 high school and collegiate pitchers using the same wearable technology utilized in this study during a structured long-toss program that included distances from 90 feet to 180 feet. Similar to our study, they found that although ball velocity increased with each distance, elbow torque did not increase beyond 120 feet. Last, a study by Dowling et al[6] used wearable technology in a group of 95 high school baseball players during a long-toss protocol from 9 m to 46 m (30 feet to 150 feet) and found an increase in elbow varus torque at longer distances that plateaued to an average torque of 36 N·m after a distance of 27 m (90 feet). Interestingly, a study by Slenker et al[25] found contrasting results; when evaluating elbow valgus loads for 29 healthy college pitchers using high-speed motion capture during a long-toss program that included distances from 18 m to 55 m (60 feet to 180 feet), they found no increase in elbow valgus loads at increasing distances.

It is important to note, however, that these studies instructed their participants to throw "hard, on a line" (or otherwise given similar guidance) at each distance of the throwing program, presumably instructing players to throw on a horizontal line and minimizing arc. This could have inadvertently resulted in participants throwing at greater-than-intended effort,[29] especially at shorter throwing distances. For this reason, UCL rehabilitation protocols often advise players to throw "on an arc" and with enough effort to reach the intended target.[24] In fact, a recent study by Melugin et al[19] evaluated the effect of reduced throwing effort on arm biomechanics while throwing at a distance of 120 feet and found a 7% decrease in elbow varus torque and 11% decrease in ball velocity for every 25% decrease in perceived effort. The average ball velocity in our study in which players were asked to crop hop throw on an arc at distances of 120 feet (58.6 mph) was comparable with the 50% effort throws performed in the study by Melugin et al (60.3 mph) and much slower than throws performed hard, on a line, in the studies by Fleisig et al[11] (83.2 mph) and Leafblad et al[17] (72.2 mph). Similarly, another study by Fleisig et al[12] found that athletes throw with an average ball velocity of 84.3 mph when performing full-effort throws at a distance of 60 feet while utilizing the crow hop, which is substantially greater than our average ball velocity of 51.0 mph when performing these same throws on an arc. These findings suggest that throwing on an arc instead of hard, on a line, greatly reduces throwing effort and has implications for reducing medial elbow torque during an interval throwing program.

Previously, it was hypothesized that the plateauing effect of medial elbow stress at the relatively short distances seen in these studies may be due, at least in part, to players using the crow hop when throwing at greater distances.[14,16] Studies have suggested that lower body kinematics have an effect on the shoulder and elbow during the throwing motion.[14,16] Thus, it was previously hypothesized that the addition of the crow hop may lead to a protective effect on the medial elbow at longer distances of throwing. For this reason, some UCL rehabilitation programs advocate addition of the crow hop at all distances of throwing, including short distances early in the protocol.[1,25-27] Our study, however, shows that there was no difference between crow hop and standing throws in elbow stress at distances greater than 60 feet; in fact, at distances up to 60 feet, players who use the crow hop actually place greater torque on the medial elbow. The authors speculate this is seemingly due to the transfer of energy through the kinetic chain and resulting increase in upper body throwing forces, as reflected by greater ball velocity at these distances.

Ultimately, the results of our study indicate that it would be prudent for players to initially perform standing throws at shorter distances and only later be allowed to employ a natural crow hop at greater distances to minimize torque placed on the medial elbow. In addition, we would advise that players initially throw on an arc to further minimize torque placed on the medial elbow.

This study has important limitations. First, there is limited evidence on the validation of the wearable technology used in this study. A pilot study involving 10 throws by 35 healthy athletes demonstrated high correlation of device measurements when compared with high-speed motion capture, with correlation coefficients in the range of 0.86 to 0.95 for all biomechanical parameters.[5] However, there have been many concerns regarding the methodology of this validation, as described in a letter to the editor by Driggers et al.[7] Boddy et al[3] recently performed a similar study with 10 healthy pitchers and found significant correlations for all measured biomechanical parameters (R = 0.653 for elbow stress), although elbow stress measurements obtained by the sensor were, on average, 38.7% lower in magnitude than those obtained by motion capture. Because the purpose of our study was to assess for relative differences in elbow stress between crow hop and standing throws, we believe that our overall findings are accurate, given our current understanding of the reliability of the device. However, it is clear that more rigorous testing against high-speed motion capture is necessary to comprehensively assess the validity of the device. Another limitation is the relatively small sample size of our cohort; however, this sample size is typical of previous pitching parameter studies. Our cohort of players were healthy and their behavior may not accurately represent players actually undergoing UCL rehabilitation protocols. Additionally, our study did not include a power analysis; thus, the lack of difference in some comparisons may be due to type II error. Last, we did not evaluate “maximum distance” throws, which may have demonstrated even greater medial elbow stress, as shown in previous studies.[11]

CONCLUSION

Crow hop throws generated greater medial elbow torque than standing throws at distances up to 60 feet; however, there were no differences in elbow torque at distances greater than 60 feet between the 2 throw types. For both crow hop and standing throws, elbow stress increased at each distance interval up to 90 feet before plateauing at distances greater than 90 feet. In conclusion, the crow hop throwing technique does not reduce medial elbow stress during a simulated interval throwing program, and it may actually increase torque at shorter throwing distances.

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