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Identifying Risk Factors of Upper Extremity Injuries in Collegiate Baseball Players: A Pilot Study

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Original Research

Identifying Risk Factors of Upper Extremity Injuries in Collegiate Baseball Players: A Pilot Study

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Background

Repetitive pitching places tremendous forces on the shoulder and elbow which can lead to upper extremity (UE) or lower extremity (LE) overuse injuries.

Purpose

The purpose of this study was to evaluate pre-season physical measurements in collegiate baseball players and track in-season baseball throwing volume to determine which factors may predict throwing overuse injuries.

Study Design

Retrospective Cohort study.

Methods

Baseline preseason mobility, strength, endurance, and perception of function were measured in 17 collegiate baseball pitchers. Participants were then followed during the course of the season to collect rate of individual exposure, estimated pitch volume, and rating of perceived exertion in order to determine if changes in workload contributed to risk of injury using an Acute-to-Chronic Workload ratio (ACWR).

Results

Participants developing an injury had greater shoulder internal rotator strength ($p=0.04$) and grip strength in a neutral position ($p=0.03$). A significant relationship was identified between ACWR and UE injuries ($p <0.001$). Athletes with an ACWR above or below 33% were 8.3 (CI_{95} 1.8-54.1) times more likely to suffer a throwing overuse injury occurring to the upper or lower extremity in the subsequent week.

Conclusion

ACWR change in a positive or negative direction by 33% was the primary predictor of subsequent injury. This finding may assist sports medicine clinicians by using this threshold when tracking pitch volume to ensure a safe progression in workload during a baseball season to reduce the risk of sustaining overuse upper or lower extremity injuries.

Level of Evidence

3b

INTRODUCTION

Tremendous forces occur on the shoulder and elbow during repetitive pitching that can lead to overuse injuries in collegiate baseball.[1,2] The injury incidence rate for shoulder and elbow injuries in the National Collegiate Athletic Association (NCAA) over a 16 year period averages 1.85 and 5.78 /1000 practice and game athlete-exposures, respectively.[3] Between the NCAA, National Association of Intercollegiate Athletics (NAIA), and National Junior College Athletic Association (NJCAA), there are an estimated 50,000 college

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baseball players.[4] Assuming the injury rate is consistent across an average of a 30 game season and 121 practices in a spring season, this would estimate 20,000 injuries to collegiate baseball players of which 45% occur to the upper extremity (UE).[3,4]

Research has identified shoulder mobility deficits, shoulder strength deficits, trunk mobility deficits, and kinetic chain considerations as a risk for future injury in baseball players.[2,5] Aragon et al[6] reported that limited trunk rotation increases the amount of load placed on the shoulder and elbow during a pitching sequence. This limited trunk mobility predisposed an individual to be up to 2.75 times more likely to sustain an injury. Limited shoulder mobility increased the odds of injury by 2.5 in professional pitchers and approximately four times more likely in high school athletes.[5,7] Pitching with a fatigued arm was a strong predictor (OR⩾4) of adolescents reporting shoulder and elbow pain.[8] Collegiate baseball pitchers also demonstrated a strong correlation (r=.72) between throwing volume and arm soreness.[9] Another overhead sport that is associated with increased risk of upper extremity overuse injuries is cricket.[10] Although throwing mechanics differ than baseball, the volume of overs, or throws, is monitored similarly to baseball.[10] Cricket bowlers' injuries were tracked over multiple years and observed 3.3 relative risk of injury associated with increased total number of balls bowled, and 2.1 relative risk when total number of balls bowled decreased from previous workloads.[10] It is clear that overuse injuries have several risk factors ranging from mobility deficits to pitch volume to consider when attempting to minimize injuries.[2,5–10]

Research results suggest that a positive relationship between training load and injury exists.[11,12] Monitoring training load throughout a competitive season allows clinicians to objectively measure changes in performance, reveal fatigue, and minimize the risk of non-functional fatigue, illness, and injury.[12] Training load is the combination of internal workload (relative biological stressors) and external workload (objective work done during athletic competition or training).[11] One method used to analyze training load is the acute-to-chronic workload ratio (ACWR).[11] This model describes acute training load (training load of one week) to chronic load (the rolling average of 4 weeks) to determine the preparedness of an athlete.[11] Mehta et al[13] showed that high school baseball pitchers with an ACWR of 1.27 (the acute workload was 27% greater than the chronic workload) were 14.9 times more likely to sustain an injury.

Pre-season and in-season upper and lower extremity injury risk factors exist in baseball pitchers, that have not been studied specifically in college baseball pitchers. Therefore, the purpose of this study is to evaluate pre-season physical measurements in collegiate baseball pitchers and track in-season baseball throwing volume to determine which factors may predict throwing overuse injuries. The primary hypothesis is that pre-season range of motion (ROM), strength, and patient perception measurements will be diminished in those who develop injuries during the season as compared to those who do not develop injuries. The secondary hypothesis is that in-season workload changes above and below a threshold will predict overuse injuries in the upper or lower extremity. This study will allow clinicians to target efforts to mitigate overuse injuries in the future.

METHODS

This retrospective cohort study has three primary components: pre-season baseline assessment, a daily pitching volume recording to examine pitch volume weekly totals, and a daily tracking of athletic exposure and treatment recording for each pitcher. This data was captured to determine if injury occurrences were associated with baseline measures or in-season throwing volume changes. This study was approved by the university institutional review board.

PARTICIPANTS

A convenience sample of 17 collegiate baseball pitchers from a single Division-I baseball program (mean ± SD age 20.1 ± 0.09 y, height 186.8 ± 26.9 cm, mass 96.5 ± 8.8 kg) participated in this study. Participants included in this study were all pitchers on the team roster in the fall of 2019. Participants were excluded from the study if their position was not solely as a pitcher. Participants were also excluded if they were under the medical care of a physician prior to the start of the study that restricted them from participation in sport. Participants were not excluded for previous injury or surgery to the throwing arm.

MEASUREMENT PROTOCOLS

Range of motion, strength, and endurance measurements were collected in November and December following the conclusion of the fall season. This time point ensured athletes were not fatigued and served as a baseline measurement as the fall season had just been completed. All measurements were collected bilaterally.

Participants were asked to fill out the Kerlan-Jobe Orthopaedic Clinic (KJOC) Shoulder and Elbow questionnaire in January, prior to the season. The KJOC Shoulder and Elbow[11] evaluates the individual's perceived level of function in performing overhead sports and is a sensitive measurement tool for detecting subtle changes in upper extremity performance.[14]

RANGE OF MOTION

All participants had their passive range of motion (PROM) assessed for shoulder external rotation, internal rotation, horizontal adduction, flexion, volar forearm compartment, and trunk rotation. Two trials were averaged to represent each measurement and all measures were taken bilaterally except for trunk rotation where three trials were averaged.[2] All measures were captured by two certified athletic trainers working directly with the baseball program and de-identified to protect athletes' privacy.

Shoulder external rotation and internal rotation were assessed with the participant positioned supine on a table with their arm abducted to 90° and elbow flexed to 90° with a rolled towel placed under the distal humerus.[15] One examiner provided scapular stabilization and applied passive motion while the other examiner measured shoulder motion with a standard goniometer. End range was determined when the first examiner began to feel the scapula rise off of the table in which they applied slight overpressure to take out the "slack" in the soft tissue.

Shoulder horizontal adduction was assessed with the participant positioned supine on a table with their arm abducted to 90° and the elbow relaxed in a flexed position.[5] One examiner stabilized the scapula from lateral gliding by applying downward pressure on the lateral border of the participant's scapula. The fulcrum of the goniometer was placed lateral to the acromion process, the stationary arm and moving arm were parallel to the lateral epicondyle of the distal humerus. The first examiner passively moves the position of the humerus into adduction until they feel the lateral border of the scapula move against their hand.

Shoulder flexion was assessed with the participant positioned supine on a table with the hips and knees flexed.[15] The fulcrum of the goniometer was placed inferior and lateral to the acromion process, the stationary arm was parallel to the trunk, and the moving arm parallel to the longitudinal axis of the humerus pointing to the lateral epicondyle of the humerus. One examiner provided inferior stabilization by applying pressure through the acromion process to maintain the position of the scapula. The participant's arm was passively elevated by one examiner until restriction is felt at the shoulder, movement deviates outside the plane of motion, or if compensatory movement consisting of lumbar extension was observed. The second examiner measures and records the angle of flexion.

Volar forearm compartment was assessed with the participant sitting upright with the shoulder flexed to 90° and the elbow fully extended.[16] The fulcrum of the goniometer was placed on the ulnar styloid, the stationary arm was parallel to the ulna, and the moving arm was parallel to the 5th metacarpal. The patient actively extends the fingers, thumb, and wrist to end range. One examiner ensures that no compensatory movement is done at other joints. The second examiner measures and records the angle of wrist extension.

Trunk rotation was assessed with the participant in a half kneeling position beginning with the right leg forward in line with the left knee.[6,17] One PVC pipe is placed directly under the participant's hips in the coronal plane. Another PVC pipe is placed interlocked behind the participant's back under their elbow with their hands on their hips. The participant is instructed to rotate their body toward the right knee without moving their pelvis or knee. Two practice trials were performed before three testing trials were performed to record a measurement. Leg position was reversed and measurement in opposite trunk rotation was taken.

STRENGTH

Shoulder strength measurements were assessed isometrically using a hand-held dynamometer (Lafayette Instrument Evaluation, 01165, Layette, IN, USA). Prone internal and prone external shoulder rotators were tested with the participant positioned prone on a table with their arm abducted at 90° and elbow flexed to 90°. Two make tests were performed asking the athlete to exert maximal force against the dynamometer which was placed 5cm proximal to the proximal wrist extension and wrist flexion crease, respectively. Shoulder elevators in the scapular plane[15,18] were assessed with the participant seated upright with their back against a wall. The arm was abducted to 90° and horizontally adducted to 45° with the forearm in a neutral "thumbs-up" position. The dynamometer is placed 5cm proximal to the proximal wrist extension crease. The participant is instructed to maximally elevate their arms for two repetitions.

Grip strength was assessed using a Jamar Technologies Hydraulic Hand Dynamometer (Patterson Medical, 5030J1, Warrenville, IL, USA) in a standard seated position with elbow flexed to 90° and forearm neutral rotation. The participant was instructed to squeeze the hand-held dynamometer with maximal contraction for two seconds following a five second break. Power position grip strength was measured in a similar manner; however, the participant was seated with the arm abducted to 90°, elbow flexed to 90°, and forearm pronated.

Two trials were averaged to represent each measurement and all measures were performed bilaterally.

Posterior shoulder endurance test was assessed as previously described by Evans et al.[19] First, the participant's body weight in pounds and arm length in centimeters were measured. Both measurements were entered into an equation to determine a hand-held weight that was used to obtain 20Nm of force. The participant was positioned prone on a table with the arm placed into horizontal abduction and externally rotated with the thumb pointing towards the ceiling while holding the weight. A metal vice grip was attached to a PVC pole to provide feedback. The participant was instructed to hold the position against the metal vice grip until failure. Failure was determined by the participant extending their trunk, not keeping their arm against the metal vice grip after one reminder, rotating the torso, or bending the elbow. The time the participant could hold the position was recorded. The procedure was then repeated on the opposite limb.

IN-SEASON FACTORS

For the secondary purpose of the study, participants were followed during the course of the season to collect rate of individual athletic exposure (Table 1), estimated pitch volume representing the external workloads, and rating of perceived exertion representing the internal workloads in order to determine if changes in workload contributed to risk of injury. Participants were asked to estimate the number of throws they completed on a daily basis in each category defined below. Participants were identified as being injured if they sustained an overuse, upper or lower extremity injury during the season requiring them to miss at least one day of participation. An overuse injury is defined as not traumatic, but rather gradually worsening, injury to the upper or lower extremity during the season.

This study defined the throwing categories based on the definitions used by Lazu et al[9]: catch, long toss, flat ground, bullpen, game day bullpen, game day pitches, and other. Catch was performed at 30-50% intensity at a distance of

Table 1: Exposure Code

0	**Off – Day of rest mandated by the NCAA or at coach's discretion**
1	Game – Participation or available to participate in a game against another team
2	Practice – Participation in team practice
3	Conditioning – Indicates that the athlete only participated in conditioning that day
4	Injured Limited – Athlete was modified during a practice due to an injury or illness
5	Injured Out – Athlete was unable to participate in a practice or game

approximately 70 feet. Long toss was performed at greater intensity at distances ranging from 120-150 feet with the intention of getting the ball to the partner on the fly or on one hop. Flat ground was thrown at 60 feet with varying intensity. Bullpen during practice varied based on the day, athlete, and coaching instructions but was performed on a pitching mound. Game day bullpen followed a similar format but with the intent of preparing the athlete to pitch in a game. Game day pitches was performed on a pitching mound in a game against another team. Other was performed during field work drills during practice with the intent to prepare for different game situations.

After each practice or game, a certified athletic trainer asked the pitchers to estimate their perceived exertion for that day's exposure and pitch volume for each of the seven categories. The Borg Perceived Exertion Scale ranging from 0 (no exertion at all) to 10 (extremely strong/heavy) was used to represent that day's internal workload.[20] The same athletic trainer recorded the athlete's exposure type (Table 1). To expedite data collection, all information was captured using a text messaging system.

DATA REDUCTION

Each day the pitch volume and RPE data was entered into GideonSoft (Horizon Performance, Raleigh, NC, USA). This software was used to store all the data collected over the course of the season for every pitcher where a spreadsheet was then generated for data analysis. All pitchers were coded to protect their identity. In excel, the daily workload was calculated by multiplying the internal by the external workload to create a unitless measure.[10,21] Each week these daily workloads were summed to represent weekly totals. The acute-to-chronic workload ratio (ACWR) was the relative change in total workload. The acute workload was represented by the current week's workload while the chronic workload included the average of the three weeks total workload (current week plus previous two weeks).[9,13,21,22] Unfortunately, the season was cut short due to the COVID-19 virus outbreak; therefore, the data collection ended in the middle of the 9th week of the season. All de-identified data were shared with the principal investigator for statistical analysis.

STATISTICAL METHODS

The frequency counts of athletic exposures were captured daily to identify participation status of a player. This allowed us to compare pre-season measurements between two groups: those that sustained an upper or lower extremity injury, requiring missing participation for at least one day (Injured) to those who did not (Non-Injured).

Preseason descriptive statistics for range of motion, strength, and outcome measures were analyzed for normal distribution using the Shapiro-Wilk test. The data was found to be normally distributed, and the pre-season data was compared between injured and non-injured groups using independent t-test with significance set at $p \leqslant 0.05$ to determine differences in pre-season measures between the two groups.

The second goal was to investigate whether in-season acute-to-chronic workload changes would precede events of overuse injuries. The initial goal was to use all the total workload values, but due to the large volume of catch throws (Table 2) and the unusually high correlation with RPE ($r=0.73$, $p<0.001$) another approach was taken.

Previous approaches have used only high intensity throws.[10] Therefore acute-to-chronic workload from games, practice and game bullpens pitches were calculated using the same external and internal workload calculation described above. Next, the threshold for percent change was determined to be 33% by examining the absolute values of percent change total workloads and events of injury using a receiver operating characteristics (ROC) curve. The threshold that provided the best balance between sensitivity and specificity was determined using the ROC coordinates. Seventeen pitchers were tracked for six weeks resulting in 101 pitcher-weeks (one pitcher tracked for five weeks) which were reviewed and the ACWR changes greater or less than 33% were identified. A cross tabulation (2x2 contingency table) using a Chi-Square and Fisher Exact test was carried out to determine the relationship between ACWR changes greater or less than 33% and if an overuse injury occurred in the next week. The relative risk ratio was calculated to determine the probability of sustaining an injury along with 95% confidence interval from the contingency table. Statistical analysis of all data was performed using SPSS Statistics version 25 (SPSS Science, Chicago, Illinois). For all statistical analyses, an alpha level of $p < 0.05$ was used. The relative risk ratio was calculated using an online calculator.[23]

RESULTS

EXPOSURES

The frequency counts of athletic exposures revealed there

Table 2: Total Throws During the 2020 Season

ID	Role	Catch	Long Toss	Flat Ground	Practice Bullpen	Game Bullpen	Game	Other	Pitch Total
BSB3	Reliever	1274	145	161	132	87	112	0	1911
BSB4	Reliever	1660	265	87	190	210	205	0	2617
BSB5	Reliever	1360	80	70	195	210	189	0	2104
BSB6	Reliever	1435	90	117	245	157	285	0	2329
BSB7	Reliever	1115	163	40	235	147	128	0	1828
BSB8	Reliever	850	480	223	150	232	217	15	2167
BSB9	Starter	1230	670	0	360	160	485	0	2905
BSB10	Reliever	840	235	5	225	0	0	0	1305
BSB11	Reliever	1700	245	0	240	215	135	0	2535
BSB13	Reliever	1545	765	70	310	190	433	0	3313
BSB15	Starter	1336	185	40	368	170	490	0	2589
BSB16	Reliever	1445	222	0	210	185	236	0	2298
BSB18	Reliever	960	585	15	230	125	160	0	2075
BSB19	Reliever	1050	350	382	165	125	296	51	2419
BSB20	Reliever	1018	0	20	300	70	65	30	1503
BSB21	Reliever	1330	55	25	205	175	335	0	2125
BSB22	Reliever	1095	860	215	90	20	14	120	2414
Total		21243	5395	1470	3850	2478	3785	216	38437
% Total		55%	14%	4%	10%	6%	10%	1%	100%

were a total of 1037 exposures in the COVID -19 truncated season with the greatest exposures occurred during practices with 590 (56.9%) exposures and the least exposures observed as being injured out with 26 (2.5%) (Table 3). The frequency counts of pitch types revealed that the most common type of pitches thrown are the catch type accounting for 55% of total pitches (Table 2). Actual game pitches (10%) and bullpen pitches prior to entry into a game (6%) accounted for relatively few number of pitches, which agrees with previous collegiate pitch counts[9] (Table 2). Due to the truncated season, due to the COVID-19 pandemic, 17 pitchers only threw 38,437 pitches averaging to 2,263 pitches per pitcher in 9 weeks of the spring season.

PRE-SEASON MEASUREMENTS

Pre-season descriptive data compared measures collected on the throwing arm to replicate similar studies.[2,5] Only two measures were found to be significantly different between groups. Players developing an injury were found to have greater shoulder internal rotator strength ($p=0.04$) and greater grip strength in a neutral position ($p=0.03$) in the dominant arm (Table 4). No significant differences in the remaining measures were revealed between the pitchers in the injured group compared to those in the non-injured group (Table 4).

IN-SEASON MEASUREMENTS

There were 101 pitcher-weeks exposures for the 17 athletes during the truncated season. As previously described, 12 /101(11.8%) weeks resulted in an overuse injury. It was identified that 10/12 weeks were preceded by an absolute threshold of ACWR>33%. The overuse injuries that were sustained included shoulder internal impingement syndrome, rotator cuff strain, elbow extensor strain (n=2), cubital tunnel neuropathy, bicep muscle strain (n=2), hip flexor strain, and a wrist flexor strain. Due to the low number of events, the Fisher exact test was interpreted to indicate a relationship exists between ACWR>33% and overuse injuries ($p=0.001$) (Table 5). The relative risk ratio revealed that athletes with an ACWR greater or less than 33% were 8.3 (CI_{95} 1.8-54.1) times more likely to suffer an overuse upper or lower extremity injury in the subsequent week compared to those whose ACWR was within 33% change.

DISCUSSION

The purpose of this study was to examine both pre-season physical measurements and in-season workload factors to identify whether these factors are indicators for increased risk of overuse upper or lower extremity injuries in collegiate baseball pitchers. Our primary hypothesis was not supported as diminished measurement differences between the two groups were not found. Of the 15 pre-season measurements, there was no difference in 13 measurements. Significant differences were found in two strength measurements, although, these differences showed that the injured group was stronger than the non-injured group. This did not agree with the primary hypothesis which stated the in-

Table 3: Exposure Data (Days)

ID	Off	Game	Practice	Conditioning	Injured Limited	Injured Out
BSB3*†	14	7	12	8	17	3
BSB4*†¥	11	4	34	5	2	5
BSB5	8	8	38	7	0	0
BSB6	6	4	41	10	0	0
BSB7*	8	5	40	7	0	1
BSB8*†	9	9	29	10	1	3
BSB9	7	4	41	9	0	0
BSB10	33	0	28	0	0	0
BSB11*†	7	4	38	9	0	3
BSB13	10	4	42	5	0	0
BSB15	6	4	42	9	0	0
BSB16*	8	6	32	7	2	6
BSB18	9	4	38	10	0	0
BSB19	9	6	35	11	0	0
BSB20†	12	0	39	10	0	0
BSB21	6	6	38	11	0	0
BSB22*†	10	0	23	5	18	5
Total	173	75	590	133	40	26
% Total	16.7%	7.2%	56.9%	12.8%	3.9%	2.5%

* - denotes injury was sustained during the season; † - denotes injury was sustained prior to the start of the season; ¥ - denotes time missed due to illness

jured group would have diminished measurements. However, incorporating in-season data revealed interesting findings in even this small sample size and truncated season. To the authors' knowledge, this is the first study that examined both preseason and in-season factors to determine their association with upper or lower extremity injuries within a collegiate level population. Previous studies[2,5,6,9,15,18,24] have identified that differences in individual mobility and strength measurements lead to increased risk of injury. Others have examined the effect of in-season workload factors and its individual effect on risk of injury in cricket bowlers and in youth, adolescent, and collegiate baseball players. [9,10,13,21,22,24]

Comparison of shoulder mobility between the injured and non-injured groups revealed no significant differences in any motion. Our findings do not agree with the findings in the studies by Wilk et al[2] and Shanley et al[5]. Wilk et al[2] found that 18% of major and minor league pitchers with a shoulder flexion ROM deficit of 5° in the throwing arm compared to the non-throwing arm were 2.8 times more likely to be placed on the disabled list than those without a deficit. Shanley et al[5] found that in high school baseball and softball players, decreases in preseason shoulder horizontal adduction (5.2°) and internal rotation (12.1° ± 11.8°) ROM were predictive of who developed an injury. A trend towards statistical significance was noted with reduced shoulder external rotation mobility ($p=0.08$) in the injured pitcher group which agrees with Camp and colleagues' findings associated with loss of shoulder external rotation and elbow injuries.[25] The current study findings are in one team over a truncated season likely accounting for different findings.

Results of previous studies suggest that strength deficits have a relationship to upper extremity injuries requiring surgery.[15] Byram et al[15] measured strength and tracked shoulder and elbow injuries and surgeries in professional baseball pitchers over a five year window. Byram et al[15] identified a trend toward significance ($p=0.051$) of predicting shoulder injury when examining the prone external rotation strength over prone internal rotation strength ratio. A lower ratio of 0.724 was associated with a 39% increased likelihood of any throwing related injury.[15] This ratio was also lower in those athletes identified in this study who developed a throwing overuse injury ($p=0.09$). The confounding finding was that the injured group was stronger in shoulder internal rotation than the non-injured group. However, relative to the Byram study,[15] both groups in this study were identified to be weaker than the 5th percentile of professional baseball pitchers. Due to this finding the relative strength balance may be more meaningful than individual strength measures.

The increased grip strength in the injured groups and the nearly significant increased power position grip strength ($p=0.13$) are interesting findings that are not easily explained. A previous study found a non-significant trend that stronger grip (>25kg) was associated with risk of elbow injuries in youth baseball players.[26] The current study examined all overuse injuries and found that six of the 12 affected the wrist or elbow suggesting that the role that strong grip plays may require future studies on larger number of subjects to determine if there is detrimental effect on

Table 4: Preseason Descriptive Data

	Injured		Non-Injured		
	Mean	SD	Mean	SD	P value
Range of Motion (degrees)					
Shoulder Internal Rotation	73	7.4	69	8.4	0.29
Shoulder External Rotation	119	3.4	124	6.8	0.10
Horizontal Adduction	24	4.7	22	4.7	0.40
Shoulder Flexion	187	5.5	186	5.4	0.90
Volar Compartment	77	9.4	78	7.7	0.66
Left Trunk Rotation	85	7.5	83	11.7	0.74
Right Trunk Rotation	87	4.7	88	10.0	0.96
Strength (kilograms)					
Shoulder Internal Rotation	19.3	2.9	15.1	3.8	0.04*
Shoulder External Rotation	17.1	2.7	14.7	2.2	0.08
External Rotation/Internal Rotation Ratio	0.89	0.06	1.0	0.14	0.09
Scaption	11.5	1.1	11.6	1.8	0.92
Neutral Grip	57.0	5.3	51.0	4.4	0.03*
Power Grip	53.9	7.5	48.8	4.6	0.13
Posterior Shoulder Endurance Test (s)	79.0	20.0	76.0	15.0	0.74
Outcome Measures					
Kerlan-Jobe Orthopaedic Clinic	82.7	11.5	91.1	7.9	0.10

SD = Standard Deviation; * = statistically different at $p < 0.05$

Table 5: ACWR and Injury contingency table

	Injured	Not injured
Greater or Less than 33% Change	10	28
Within a 33% Change	2	61

overuse injuries.

The use of patient-reported outcomes at baseline assessment prior to injury is relatively novel but has shown differences between those who did not have an injury history and those with an injury history that may have some underlying issues.[27] Franz et al[14] established normative data for KJOC scores using 203 major and minor league players. This study demonstrated differences in scores between players with a history of shoulder or elbow injury (86.7 ± 14.3) compared to players with no history of injury (96.9 ± 5.0) ($p < 0.001$).[14] A similar trend was noticed with KJOC scores in the current study. The injured group's KJOC scores (82 ± 11) were lower than the non-injured group (91 ± 8) which was trending towards significance ($p = 0.10$). The limited sample limits interpretation of these findings but it appears worth further investigation to assess the ability of the player to tell whether they are likely to develop a future injury.

Collecting data throughout the season using acute to chronic workload ratio to examine changes in training volume has recently become a popular measure to predict injuries.[9,10,13,21,22,24] Previous research in baseball is limited but has identified a potential relationship between arm soreness and workload changes in a group of 7 collegiate pitchers.[9] This current study expanded with more pitchers and now tracking injuries not just arm soreness. Previous research has used threshold scores ranging from 25%-200% ACWR.[10,13,21] The ROC curve analysis from the current study determined that a 33% threshold would be an appropriate threshold to use. This threshold is consistent with previous baseball workload research that showed that changes of 27% revealed that baseball players were 14.9 times more likely to sustain an injury when this amount of change occurred.[13] The previous findings are consistent with the current study identifying an eight-fold increased likelihood of injury in baseball pitchers when workload was greater or less than 33%. The current study purposefully examined both increases and decreases in workload ratios as the literature has indicated that both a positive and negative training spike may predispose athletes to developing musculoskeletal injuries.[10,13,21] This study observed 12 pitcher-weeks with injury and an even split of six were due to negative training and six were due to increased stress that preceded injury. The results indicate that changes in pitch volume were seen to have a greater influence regarding ACWR in the time leading to injury. It appears that changes in both directions can alter tissue's ability to adapt to workloads placed on the upper and lower extremity in pitchers and should be considered in restarting activity following long layoffs.

LIMITATIONS

The primary limitation of this study was that large number of subjects and injuries are often needed to see differences which did not occur in this study. Baseline data was only collected once prior to the start of the season. Collecting measurements throughout the season may have identified if changes in measurements could have influenced the risk of sustaining an injury. Pitch counts were recorded estimates instead of actual pitch counts due to limited resources to capture every pitch. The risk of in-season injury was only examined during a singular season which resulted in a truncated season of only 9 weeks due to COVID-19. This study only examined chronic, overuse injuries and could have included acute, traumatic injuries as well. More weekly exposures are needed as the confidence interval suggest that our estimates may be more by chance than reality. Future studies should consider collecting preseason measurements and in-season factors over multiple years with the hopes of analyzing larger data sets to further examine results.

CONCLUSION

The findings of this research suggest that ACWR change in a positive or negative direction by at least 33% was the primary predictor of subsequent injury. The authors believe that this finding may assist sports medicine clinicians by using this threshold when tracking pitch volume to ensure a safe progression in workload during a baseball season in order to reduce the risk of sustaining overuse upper or lower extremity injuries, however, this should not be the only intervention strategy utilized. Significant differences including increased shoulder internal rotation strength and grip strength in the injured group were identified in this pilot study. The current study findings do not agree with previous literature, so caution with interpretation should be taken. This study serves as pilot data that suggest further acquisition of prospective data across more years may provide collegiate baseball teams with information to reduce injury risk to the upper or lower extremity as they progressively increase or decrease training volumes.

CONFLICT OF INTEREST

No conflicts of interest to report.

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