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Stress sonography of the ulnar collateral ligament of the elbow in professional baseball pitchers: a 10-year study.

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1 **Stress Sonography of the Ulnar Collateral Ligament of the**

2 **Elbow in Professional Baseball Pitchers:**

3 **A 10 Year Experience**

4
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23 **Abstract**

24 **Background:** Injury to the ulnar collateral ligament (UCL) of the elbow is potentially career threatening for elite
25 baseball pitchers. Stress ultrasound (SUS) of the elbow allows for evaluation of both the UCL and the ulnohumeral
26 joint space at rest and with stress.

27 **Hypothesis:** Stress ultrasound can identify morphologic and functional UCL changes and may predict risk of UCL
28 injury in elite pitchers.

29 **Study design:** Cross-sectional study; level of evidence III

30 **Methods:** Three hundred and sixty-eight asymptomatic professional baseball pitchers underwent preseason SUS of
31 their dominant and non-dominant elbows over a 10-year period (2002–2012). Stress ultrasounds were performed in
32 30° of flexion at rest and with 150 Newton of valgus stress by a single musculoskeletal radiologist. Ligament
33 thickness, ulnohumeral joint-space width, and ligament abnormalities (hypoechoic foci and calcifications) were
34 documented. Players who subsequently incurred a UCL injury had prior SUS findings compared to the
35 asymptomatic players.

36 **Results:** There were 736 SUS studies. Mean UCL thickness in the dominant elbow (6.15mm) was significantly
37 greater than the non-dominant elbow (4.82 mm; $P < 0.0001$). The dominant-elbow stressed ulnohumeral joint-space
38 width (4.56mm) was statistically greater than the non-dominant elbow (3.72 mm; $P < 0.02$). In the dominant arm,
39 hypoechoic foci and calcifications were both statistically more prevalent (28% vs. 3.5% and 24.9% vs. 1.6%,
40 respectively; $P < 0.001$). In the 12 players that incurred a UCL injury, there were non-significant increases in
41 baseline ligament thickness, ulnohumeral joint-space gapping with stress, and incidence of hypoechoic foci and
42 calcifications. One hundred and thirty-one players had more than one SUS with an average increase of .78 mm in
43 joint-space gapping with subsequent evaluations.

44 **Conclusion:** Stress ultrasound indicates that the UCL in the dominant elbow of elite pitchers is thicker, more likely
45 to have hypoechoic foci and/or calcifications, and has increased laxity with valgus stress over time. Players with a
46 UCL injury may have increased baseline SUS abnormalities in their dominant elbow compared to asymptomatic
47 players.

48

49 **Keywords:** baseball; stress elbow ultrasound; ulnar collateral ligament

50 **What is known about the subject:** UCL injuries of the elbow in professional baseball pitchers can be debilitating
51 and, in certain cases, career-ending. Stress elbow ultrasound is a safe, fast, and noninvasive imaging modality that
52 has been used to demonstrate structural and functional abnormalities of the UCL.

53
54 **What this study adds to existing knowledge:** Stress elbow ultrasound has the ability to detect anatomic changes to
55 the UCL in asymptomatic, professional baseball pitchers. These changes progress over time and persist with
56 continued exposure to pitching at an elite level. Currently, it is not known for certain if these changes are adaptive or
57 detrimental, but with continued longitudinal surveillance, it may be possible that stress elbow ultrasound can
58 identify asymptomatic pitchers at risk for future UCL injury.

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78 **Introduction**

79 Overhand athletes exert tremendous forces through the medial elbow joint during the act of throwing. The ulnar
80 collateral ligament (UCL) of the elbow, more specifically its anterior band, is the primary soft-tissue stabilizer to the
81 valgus stress of throwing in these athletes (5,29). Over time, the extreme repetitive stress of throwing, especially in
82 the elite baseball pitcher, may lead to either acute injury or chronic, progressive damage to the elbow and, more
83 precisely, to this ligament. Current diagnosis of injury to the UCL relies on history and physical examination as well
84 as radiographic imaging, which often assists in confirming the diagnosis of UCL injury. Typically, imaging workup
85 of the elbow includes plain radiography, stress radiography, and magnetic resonance imaging (MRI) with or without
86 enhancement (2,7, 9, 31, 34). Plain radiography may precisely define bony changes such as osteophytes, cystic
87 changes, joint-space narrowing, or loose bodies (2,31, 34), but it does not provide any direct information on soft-
88 tissue injury. In addition, it is a static test with the elbow in one position for each view obtained. Stress radiography
89 has been proposed as a more precise, functional way of evaluating UCL laxity (15, 26,35), but it also does not
90 provide direct assessment of the ligament, may be cumbersome to use, and may be provider dependent (32).
91 Conventional MRI provides excellent visualization of acute ruptures of the UCL (4,19) but may be less precise for
92 partial-thickness injury (12, 23, 37). Magnetic resonance arthrography (MRA) has been proposed as a more accurate
93 technique for partial or chronic UCL injury (12, 23, 37), but MRA has several limitations, including expense, length
94 of study time, and invasiveness (12, 23, 32, 37). Quite often, elite level pitchers are extremely reluctant to have
95 contrast injected into their injured, dominant elbow. In addition, MRA is a static imaging technique; though it may
96 clearly identify irregularities in the UCL, it does not provide any dynamic assessment of ligament laxity because the
97 player's elbow is in one position throughout the procedure.

98
99 Stress ultrasound (SUS) is a unique imaging technique that directly visualizes the UCL and allows assessment of
100 ligament laxity as related to joint-space gapping with stress (24, 29, 32, 36) (Figure 1A,B). The ability of this
101 technique to precisely visualize the UCL of the elbow with a cadaveric evaluation has been previously determined
102 (32) . Additionally, the early results of this technique in major league baseball pitchers have identified it as a low-
103 cost, quick, and noninvasive imaging modality for the UCL (32). Moreover, it allows an evaluation of UCL laxity
104 by applying stress, either manually or instrumented, to assess the amount of joint space gapping as compared to the
105 contralateral elbow (32,36).

106 Injury to the UCL of elite baseball pitchers may occur either acutely or with chronic repetitive stress (7, 9, 11). In
107 chronic, progressive injuries, there may be a point when structural changes in the UCL of the dominant elbow are
108 not yet symptomatic but detectable by SUS. Preliminary data has identified such changes as hypoechoic foci,
109 calcifications, and joint gapping in asymptomatic elite pitchers (32). The purpose of this current study was to
110 identify morphologic changes on SUS in a large study population of pitchers and determine if these changes
111 progress with continued exposure to pitching at an elite level. In addition, we aimed to compare the SUS changes
112 noted in those elite pitchers who subsequently incurred a clinically symptomatic UCL injury with the SUS findings
113 of the remaining, asymptomatic pitchers. Most importantly, our goal was to determine if SUS may provide a
114 predictive risk of UCL injury in elite level baseball pitchers as related to a particular level of morphologic and
115 dynamic abnormalities identified by this imaging technique.

116

117 **Material & Methods**

118 *Study Population*

119 A total of 736 SUS studies were performed on the elbows of 368 professional baseball pitchers during minor league
120 spring training over a 10-year period (March 2002 to March 2012). The mean age of the pitchers was 22.8 years
121 (range, 17–34 years). All pitchers were members of the same professional baseball team and were evaluated with
122 SUS during their spring training pre-participation examination. The subjects had an average professional baseball
123 experience of 2.5 years (range, 0–14 years). There were 278 (76%) right-handed pitchers and 90 (24%) left-handed
124 pitchers. All pitchers were asymptomatic at the time of their studies. The SUS studies were all obtained at the
125 request of the head team physician as a baseline scan for comparison if any of the pitchers were to subsequently
126 incur a UCL injury during the season. Institutional review board approval had been obtained, and all subjects
127 provided written informed consent.

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134 *Imaging Technique*

135 All subjects were imaged by the same experienced sonologist with a multifrequency 13-MHz linear-array transducer
136 (SonoSite MicroMaxx or M-Turbo; SonoSite, Bothell, WA) and standard acoustic coupling gel. Subjects were
137 seated, and their right elbow was placed at 30° (as measured with a digital goniometer and the longitudinal axes of
138 the forearm and upper arm) in a standardized instrumented device (Telos, Marburg, Germany). This elbow flexion
139 angle was selected for two reasons: 1) the UCL has been demonstrated to be the primary restraint against valgus
140 stress at 30° of elbow flexion and, 2) appropriate application of stress using the standardized stress device can only
141 be consistently applied at lower degrees of elbow flexion (the players' elbows could not be appropriately positioned
142 in the stress device at flexion angles greater than 60 degrees). The thickness of the anterior band of the UCL at its
143 midportion and the width of the ulnohumeral joint space at the level of the anterior band were measured both at rest
144 and with 150 Newtons of stress applied (Figure 2A-D). All images were evaluated for echotextural abnormalities,
145 including hypoechoic foci and calcifications (Figure 3). The calcifications were defined as hyperechoic foci that
146 demonstrated acoustic shadowing (32). All electronic caliper measurements (thickness at rest and stress, joint space
147 at rest and stress) and gray-scale echotextural findings were transcribed to a computer spreadsheet (Excel;
148 Microsoft, Redmond, WA) for later analysis. These measurements were taken once by the sonologist on the
149 ultrasound screen utilizing electronic calipers with a precision of 0.1 mm. The same measurements were obtained
150 for the left elbow in the same sequence. All the SUS studies were videotaped on the ultrasound monitor, and still-
151 frame images of the measurements were recorded on optical disks. During the SUS studies and the image
152 interpretation, the sonologist was blinded to each pitcher's arm dominance.

153

154 *Statistical Analysis*

155 A retrospective cohort study was performed using prospectively collected data, assessing all players with more than
156 one SUS scan during the study period with respect to all evaluated parameters. Players who subsequently incurred a
157 UCL injury had their prior SUS scan findings compared to the remaining asymptomatic group of pitchers.
158 Univariate statistical analysis with independent sample *t* test was used for all continuous variables. Continuous
159 variables included 1) ligament thickness with and without stress in dominant and non-dominant elbows, 2)
160 ulnohumeral joint space with and without stress in dominant and non-dominant elbows, 3) correlation of gray-scale
161 abnormalities with years in professional baseball, 4) ligament thickness and joint space data between the

162 subsequently injured subgroup and the asymptomatic subgroup. Categorical variables including hypoechoic foci and
163 calcifications in dominant and non-dominant elbows were analyzed with chi-squared statistic and Fisher exact test.
164 Correlated analysis was performed comparing initial versus final SUS findings of the dominant elbows in all
165 pitchers with more than one ultrasound. Finally, we conducted a Spearman Rank correlation coefficient analysis to
166 examine the relationship between ligament thickness and joint space width with stress. In determining whether or
167 not potential predictors could be obtained with respect to injury, a post-hoc power analysis was performed. Results
168 were considered statistically significant if the P value was < 0.05 . Independent sample t-test was used, and STATA
169 (v. 11.0) statistical software (StataCorp, College Station, TX) was used to perform all the analysis.

170

171 **Results**

172 *UCL Thickness*

173 Data on thickness of the anterior band of the UCL for all pitchers are listed in Table 1. At rest, the mean thickness of
174 the UCL was 6.15 mm in the dominant elbows and 4.82 mm in the non-dominant elbow. This difference was
175 statistically significant ($P=<0.001$).

176

177 *Ulnohumeral Joint Space*

178 Data on joint space width for all pitchers are listed in Table 2. The joint space width at rest was 3.32 mm in the
179 dominant elbow and 2.94 mm in the non-dominant elbow. This was not statistically significant. When stress was
180 applied, however, the joint space width of the dominant elbow was statistically greater ($P < 0.003$) than the non-
181 dominant elbow, with values of 4.56 mm and 3.72 mm, respectively. The average change in joint space width,
182 defined as the width of the ulnohumeral joint space with stress minus that at rest, was 1.24 mm in the dominant
183 elbow and .78 mm in the non-dominant elbow. The difference between dominant and non-dominant elbows was
184 statistically significant ($P = 0.004$). Using Spearman Rank correlation analysis, we noted a positive, although weak,
185 correlation between ligament thickness and joint space width stressed.

186

187 *Echotextural Abnormalities*

188 The prevalences of hypoechoic foci and calcifications in the anterior band of the UCL of all pitchers are listed in
189 Table 3. Hypoechoic foci were detected in 103 (28%) of the dominant elbows and 13 (3.5%) of the non-dominant

190 elbows of all 368 pitchers. Calcifications were noted in 92 (24.9%) of the dominant elbows and 6 (1.6%) of the
191 nondominant elbows of all 368 pitchers. The prevalences of both hypoechoic foci and calcifications were
192 statistically greater in the dominant elbow compared to the nondominant elbow ($P < 0.001$ for both).

193

194 *Longitudinal Changes and UCL Injury*

195 During the study period, 131 pitchers (36%) had more than one SUS scan (Table 4). Thirty-five of the 131 (26%)
196 were noted to have an average increase of 0.78 mm joint-space gapping (increase in ulnohumeral joint space) with
197 stress on subsequent SUS studies. There was no significant progression noted on subsequent SUS studies with
198 respect to hypoechoic foci or calcifications. Twelve of the 368 pitchers (3.3%) incurred an injury to the UCL during
199 the study period. These pitchers had a specific event resulting in symptoms, physical findings, and MRA
200 documenting partial or complete anterior band UCL damage. The baseline SUS studies of these 12 pitchers, prior to
201 their injury, were compared to the remaining, asymptomatic 356 pitchers with respect to all data parameters. The
202 comparison data for the injured and asymptomatic subgroups are listed in Table 5.

203 We observed increased ligament thickness (6.84 mm vs. 6.11 mm), joint-space gapping with stress (4.5 mm vs. 4.09
204 mm), and proportion of players with hypoechoic foci (42% vs. 29.4%) and calcifications (25% vs. 24%) in the 12
205 injured players compared to the asymptomatic 356 players. However, given the small number of UCL injured
206 players during the study period, we were unable to find any significant relationship between the presence of these
207 changes and subsequent UCL tearing. Of the 131 pitchers with more than one SUS scan during the study period,
208 nine subsequently incurred a UCL injury. There was no significant difference in progression of joint-space gapping,
209 hypoechoic foci, or calcifications between those nine players with UCL injury and the other 119 players who
210 remained asymptomatic.

211

212 **Discussion**

213 This study supports the hypothesis that SUS can identify morphologic changes of the UCL in elite pitchers as well
214 as evaluate the ulnohumeral joint-space width at rest and with stress. At the present time, SUS is unable to allow a
215 determination of relative risk of future UCL injury in this population.

216

217 Overhand athletes exert tremendous forces through the medial elbow joint during the act of throwing. UCL injuries
218 were first recognized and described by Waris in a series of 17 javelin throwers in 1946 (35). More recently, UCL
219 injuries have gained increasing attention in the medical and lay press in regards to their effect on elite baseball
220 pitchers. Once thought to be a career-ending injury for these athletes, a novel surgical technique, developed by Jobe
221 in 1974, allows for successful return to competition (22). Despite improvements in training and conditioning,
222 diagnostic methods, and surgical treatment, the incidence of injuries among pitchers has been slowly increasing in
223 recent years (11). Pitchers with UCL injuries, in particular, are often placed on the “disabled list,” which requires
224 them to rest from competition for a minimum of 15 days. More importantly, if surgical treatment is required it may
225 take as long as 12–18 months to return to previous level of competition (3,6,14, 20).

226
227 Injuries to the anterior band of the UCL may occur either acutely or chronically (7,9,11). In either situation, injuries
228 are often diagnosed by history, physical examination, and radiographic imaging, and if they are near complete or
229 complete, most require surgical reconstruction in the elite level pitcher. Although imaging tests are often used to
230 help corroborate the findings on history and physical examination, chronic injuries may have a more insidious onset
231 and may be a diagnostic challenge. Asymptomatic, elite-level throwers may have baseline progressive, adaptive
232 changes in the UCL on imaging studies that may not correlate with the future risk of injury (24, 25). Wright et al
233 used plain radiographs to examine a cohort of 56 asymptomatic professional baseball pitchers and found that
234 degenerative changes developed over time, but these changes did not correlate to time spent on the Major League
235 Baseball disabled list or risk of future injury (41). In addition, it is difficult for plain radiographs to accurately assess
236 the structural integrity of the UCL or detect any associated soft-tissue injury. Conventional MRI provides excellent
237 visualization of complete tears of the UCL, heterotopic calcification, flexor-pronator inflammation, and associated
238 bony edema (19, 23, 31,34, 37). The addition of contrast to conventional MR imaging has increased detection of
239 partial and subtle chronic injuries to the UCL; however, expense, length of time, invasiveness, and patient reluctance
240 has made its routine use in elite-level pitchers less desirable (12, 23, 32, 37). Magnetic resonance imaging, with or
241 without arthrography, also does not provide any functional or dynamic assessment of the ligament.

242
243 The UCL of the elbow, specifically its anterior band, is the primary soft-tissue stabilizer to the valgus stress with
244 throwing (5,30). An imaging modality that can accurately evaluate the UCL in a stressed position may provide more

245 useful information than one that evaluates the UCL in a fixed, extended position as is the case with plain
246 radiography and MRI. Rijke et al have used a calibrated device to produce a valgus stress during radiography to
247 evaluate patients with UCL injuries (35). Lee et al used radiography to compare the amount of ulnohumeral joint-
248 space gapping with and without stress in “normal” individuals. They found a significant difference in the amount of
249 gapping when 5 lbs of valgus stress was applied at 0° and 30° elbow flexion. There was no difference, however, in
250 gapping whether they looked at the non-dominant or dominant elbow (26). Ellenbecker et al performed a similar
251 study, but looked specifically at uninjured, professional baseball pitchers. They found a significantly greater
252 difference in the amount of ulnohumeral joint-space widening with stress when comparing the dominant to non-
253 dominant elbows. They concluded that increased medial elbow laxity exists in the dominant arms of uninjured
254 pitchers (15). Despite providing a functional assessment of the ulnohumeral joint space, these reports utilizing plain
255 radiography cannot simultaneously comment on the structural properties of the UCL or surrounding soft-tissue
256 structures, which are also functionally important factors.

257
258 Elbow ultrasound is a useful imaging modality to detect injuries of the bony and soft-tissue structures of the elbow,
259 including tendons, ligaments, muscles, bursae, and neurovascular structures. It is also safe, rapid, non-invasive, non-
260 radiating, and inexpensive for therapeutic, guided injections and can be used in patients with claustrophobia or
261 positioning difficulties (27, 28, 38). Furthermore, it has been shown to be effective in detecting both partial- and
262 full-thickness tears of the UCL, echotextural abnormalities (hypoechoic foci and calcifications), and ulnohumeral
263 osteophytes (13, 24, 29, 32, 39). The contralateral extremity is readily accessible for comparison, and, most
264 importantly, a stress device can be used to provide a measured dynamic and functional assessment of the UCL (13,
265 36, 39). Wood et al (40) (1 patient) and DeSmet et al (13) (2 patients) reported cases of collegiate-level baseball
266 pitchers who sustained UCL injuries diagnosed on SUS. In all cases, they were able to demonstrate medial valgus
267 instability with appropriate stress, and images of the contralateral elbow were obtained for comparison. They were
268 able to accurately detect UCL injury in all cases that were later confirmed at the time of surgical reconstruction.
269 Sasaki et al performed SUS on 30 asymptomatic, collegiate baseball players (36). They showed that the ulnohumeral
270 joint space of the dominant elbow was significantly wider than that of the non-dominant elbow and that increased
271 laxity occurred with valgus stress. Their SUS methods were slightly different than the current study as they placed
272 the elbow in 90° flexion, used gravity stress instead of manual stress, and did not comment on the actual qualitative

273 characteristics of the UCL. In addition, only 12 of the players in their cohort were pitchers. In a previously published
274 study, SUS was performed on 26 asymptomatic, professional pitchers. The results of this study showed that the
275 anterior band of the UCL was thicker, more likely to have echotextural abnormalities, and had increased laxity with
276 valgus stress in the dominant elbow of these pitchers (32).

277
278 The valgus stress applied to all elbows during this study was standardized by utilizing the Telos stress device. This
279 allowed a consistent force to be applied, thereby eliminating a potential source of variation. Studies suggest that
280 during the late cocking/acceleration phases of throwing, when the UCL is subjected to the highest valgus stress, the
281 elbow is at 60-90° of flexion (1, 8, 7, 9) Theoretically, testing the elbow at 60-90 degrees of flexion with the Telos
282 device would most closely approximate the clinical setting. The proper use of this device, however, requires that the
283 elbow be placed within a narrow, low range of elbow flexion so that the fixation pads contact the players forearm
284 and upper arm. This assures that the exact amount of stress is applied to the medial elbow. This required positioning,
285 however, did not allow the players' elbows to be placed at 60-90 degrees of flexion. And so, because of the variation
286 in elbow flexion in the late cocking/acceleration phases of throwing, the limitations of proper Telos use, and
287 previous biomechanical studies that have identified the UCL as the primary restraint against valgus stress at 30° of
288 elbow flexion, this elbow flexion angle was subsequently chosen for all testing (30).

289
290 In the current study, we noted baseline anatomic changes of the UCL in the dominant elbows of elite-level baseball
291 pitchers. We found that the mean thickness of the UCL was significantly greater in the dominant compared to the
292 non-dominant elbow. We also found that the gapping of the stressed ulnohumeral joint space was significantly
293 greater in the dominant elbow. Echotextural abnormalities were more likely to be present in the dominant elbows of
294 the pitchers as well. These changes in UCL thickness, joint space gapping with stress, and echotextural
295 abnormalities may be adaptive and secondary to repetitive throwing. The current study is unable to determine if their
296 presence may or may not predispose pitchers to subsequent UCL injury. Despite this, these findings serve as a
297 baseline for medical caretakers of these players for comparison if subsequent UCL injury does occur. In addition,
298 SUS may also be beneficial for medical caretakers in scenarios where surgical treatment is being contemplated, such
299 as for those pitchers found to have partial tearing on MRI arthrogram, those with medial elbow pain who have had
300 previous UCL reconstruction, and those who are having difficulty despite adequate non-operative treatment.

301 Hopefully, with further data collection and continued longitudinal surveillance, whether or not these findings
302 correlate with risk of future UCL injury may possibly be determined.

303
304 The strengths of this study include the size of the study group and the length of the study period. It represents the
305 largest and longest clinical study on the use of SUS for the evaluation of the UCL in professional baseball pitchers.
306 In addition, the current study extended over a 10-year time period, and we were able to obtain multiple years of SUS
307 studies for more than one third of our athletes. It provides both quantitative assessment of the UCL with a
308 standardized stress device and qualitative assessment of UCL ultrastructural changes with throwing. Furthermore, all
309 ultrasound data collected over the entire 10 year study period was obtained by the same experienced musculoskeletal
310 ultrasonographer.

311
312 There were a few limitations in this study. There was no independent control group of non-overhand throwing
313 athletes. However, we were able to use the non-dominant elbow as a suitable control. Secondly, there were a
314 relatively small number of throwers with injured UCLs during the study period that could be used as a subgroup
315 comparison to non-injured throwers. Only 12 pitchers required a UCL reconstruction during the 10-year study
316 period. This low number of UCL reconstructions, although good for the baseball organization, did not allow any
317 statistical significance to be achieved during this study period. An increased number of players requiring UCL
318 reconstruction would have made these observed results statistically significant (post-hoc analysis revealed that with
319 a sample size of 17 subjects, the findings would have approached statistical significance.) We will continue to
320 collect data to amass larger numbers of UCL injuries in efforts to identify possible risk factors, such as increased
321 ligament thickness, change in ulnohumeral joint space with stress, and presence of echotextural abnormalities.
322 Thirdly, only 131 (36%) of the pitchers remained with the team long enough to have more than one SUS during the
323 study period. This, however, is unavoidable when studying professional baseball pitchers as the nature of the sport
324 often dictates that players change teams frequently. Moreover, we did not have any pitching history data pertaining
325 to skill level, position in the rotation and pitch counts. Several reports have shown that these factors play a role in
326 the incidence of elbow pain, elbow injury, and need for elbow surgery in youth and adolescent pitchers. It is possible
327 that these unknown factors may have had an effect on our results. (16-18, 33) Lastly, since our data was obtained
328 from asymptomatic individuals, it is difficult to say with certainty if these observed abnormalities on SUS correlate

329 with clinical symptoms and instability. Despite this, our study has shown that SUS can be used for long-term
330 surveillance of the elbows of elite level pitchers.

331

332 *Summary*

333 We have shown that SUS can detect anatomical changes to the UCL in asymptomatic, professional baseball
334 pitchers. These abnormalities progress over an extended period of time and persist with continued exposure to
335 pitching at an elite level. We were unable to determine if these abnormalities are directly associated with risk of
336 future UCL injury due to a low number of UCL reconstructions performed over the 10-year study period. With
337 continued longitudinal surveillance, we hope to precisely define risk factors on SUS for future UCL injury in this
338 athletic population.

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435 **Figure Legends**

436 **Figure 1.** Bilateral ultrasound images of the ulnar collateral ligament (UCL) in an asymptomatic professional
437 baseball pitcher. A) Image of the nonpitching arm shows a normal UCL (arrow). B) Image of the pitching arm
438 shows a slightly thicker UCL that contains a hypoechoic focus (arrow). E, medial epicondyle; T, trochlea; C,
439 coronoid process.

440 **Figure 2.** Clinical and ultrasound images at rest and with valgus stress in the pitching arm of an asymptomatic
441 professional baseball pitcher. A) Photograph demonstrating stress ultrasound of elbow in Telos device. B)
442 Photograph demonstrating valgus stress being applied to elbow by Telos device. C) At rest, the ulnohumeral joint
443 (asterisks) measures 4.2 mm. D) With valgus stress applied by the Telos device, the ulnohumeral joint (asterisks)
444 widens to 7.9 mm. T, trochlea; C, coronoid process.

445 **Figure 3.** Ultrasound images of the pitching arm of an asymptomatic professional baseball pitcher. Calcifications
446 (arrowheads) are seen within a thickened, hypoechoic ligament. E, medial epicondyle; T, trochlea; C, coronoid
447 process.

448 **Table 1.** Thickness in millimeters of the anterior band of the UCL in the dominant and nondominant elbows of all
 449 pitchers at rest.

| 451 Thickness | Dominant | Non-Dominant | P value |
|---------------|------------------|------------------|---------|
| 453 At Rest | 6.15 +/- 1.57 mm | 4.82 +/- 1.32 mm | <.001 |

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 456
 457 **Table 2.** Joint space width in millimeters of the anterior band of the UCL in dominant and non-dominant elbows of
 458 all pitchers at rest, with Telos stress, and the difference.

| 460 Joint Space | Dominant | Non-Dominant | P value |
|--------------------------------|------------------|-----------------|---------|
| 462 At Rest | 3.32 +/- .07 mm | 2.94 +/- .12 mm | .61 |
| 463 With Stress | 4.56 +/- 1.10 mm | 3.72 +/- .92 mm | <.003 |
| 464 Difference (stress – rest) | 1.24 +/- 1.04 mm | .78 +/- .65 mm | <.004 |

467 **Table 3.** The prevalences of hypoechoic foci and calcifications in the anterior band of the UCL
 468 in the dominant and non-dominant elbows of all pitchers.

| | Dominant | Non-Dominant | P value | X ² (DF) |
|--------------------|-----------|--------------|---------|---------------------|
| | N (%) | N (%) | | |
| 473 Hypoechoic | 103 (28) | 13 (3.5) | <.001 | 10.7(2) |
| 474 Calcifications | 92 (24.9) | 6 (1.6) | <.001 | 7.1(1) |

476 X² = Chi-square; DF = degree of freedom

477 **Table 4.** Change over time between initial and final SUS characteristics of 131 pitchers who had at least 2 yearly
 478 ultrasounds.

| | Initial | Final | P value | 479 |
|--|------------------|------------------|----------------|--------------------------|
| | Mean (SD) | Mean (SD) | | 480 |
| Thickness (at rest) | 6.05 +/- 1.44 mm | 6.12 +/- 1.60 mm | .62 | 481 |
| Joint space (at rest) | 3.08 +/- .74 mm | 2.96 +/- .73 mm | .11 | 482 |
| Joint space (stressed) | 4.00 +/- 1.12 mm | 4.37 +/- .99 mm | .001 | 483 |
| Change in joint space (stressed-rest) | 1.17 +/- .96 mm | 1.03 +/- .72 mm | .06 | 484 485 |
| | | | | 486 |
| | N(%) | N(%) | P value | X²(DF) |
| 487 Hypoechoic foci | 65 (49) | 70 (53.4) | .65 | 8.37(1) |
| 488 Calcifications | 40 (30.5) | 35 (26.7) | .24 | 24.9(1) |
| 489 | | | | |

491 X² = Chi-square; DF = degree of freedom

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505 **Table 5.** Comparison of baseline SUS studies of the anterior band of the UCL in the dominant elbows of pitchers
 506 with subsequent UCL injury and those pitchers remaining asymptomatic.

| | Injured (n = 12) | Asymptomatic (n = 340) | P value | |
|--|------------------|------------------------|---------|---------------------|
| | Mean (SD) | Mean (SD) | | |
| Thickness (at rest) | 6.84 +/- 1.56 mm | 6.11 +/- 1.57 mm | .19 | |
| Joint space (at rest) | 3.44 +/- 1.34 mm | 3.08 +/- 1.77 mm | .44 | |
| Joint space (stressed) | 4.55 +/- 1.52 mm | 4.09 +/- 1.25 mm | .44 | |
| Change in joint space (stressed-rest) | 1.06 +/- .88 mm | 1.12 +/- .95 mm | .83 | |
| | | | | |
| | N(%) | N(%) | P value | X ² (DF) |
| Hypoechoic foci | 5(42) | 100(29.4) | .17 | 1.90(1) |
| Calcifications | 3(25) | 81(24) | .68 | .17(1) |

519 X² = Chi-square; DF = degree of freedom

520