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The pathoanatomy of the anterior bundle of the medial ulnar collateral ligament

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Background: The purpose of this study was to increase our understanding of the pathoanatomy of the ulnar collateral ligament (UCL) by performing a descriptive analysis of the surgical inspection of the anterior bundle in patients undergoing reconstruction.
Methods: A single-surgeon series of 163 patients who underwent UCL reconstruction between 2009 and 2017 was retrospectively analyzed. Descriptions of the pathoanatomy of injury were obtained from the operative reports. Magnetic resonance imaging data were reviewed to assess whether the presence and location of tissue disruptions were accurately recognized. Demographic and clinical characteristics were obtained from medical records and correlated to observed pathoanatomy.
Results: Injuries to the anterior bundle were characterized by a single tissue disruption (65%), tissue disruptions at more than 1 location (23%), or injuries without distinct fiber tissue disruptions (12%). The presence and location of tissue disruptions matched magnetic resonance imaging findings in 124 of 153 patients (81%). Partial tears more frequently affected the anterior band of the anterior bundle distally as opposed to the posterior band of the anterior bundle proximally ($P = .012$). Patients with single tissue disruptions more frequently reported a popping sensation than patients with non-tear insufficiency ($P = .030$).
Conclusions: This study shows the heterogeneity of anterior bundle injuries in patients undergoing UCL reconstruction. A variety of injury configurations and chronic attritional damage to the anterior bundle were observed, as well as distinct tear patterns at the distal and proximal attachment sites. Future research may elucidate the diagnostic value of a pop sign for UCL injury.
Level of evidence: Anatomy Study; In Vivo and Imaging

Keywords: Elbow; medial ulnar collateral ligament; anterior bundle; pathoanatomy; anterior band; posterior band; pop

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Overhead and upper-extremity weight-bearing athletes, such as baseball pitchers, tennis players, and gymnasts, are at an increased risk of medial ulnar collateral ligament (UCL) injury. The UCL is located on the medial side of the elbow and consists of the anterior, posterior, and transverse bundle (Fig. 1). The anterior bundle of the UCL connects the sublime tubercle (ulna) and the anteroinferior part of the medial epicondyle (humerus), serving as the main restraint to valgus and torque forces applied to the elbow.[4,8,10,14] The anterior bundle can be further subdivided into an anterior and posterior band, with different strain patterns through elbow range of motion.[12,23] As tremendous valgus and torque forces are applied to the medial side of the elbow during overhead and weight-bearing athletic activities, the anterior bundle is the UCL's structure at risk of injury in these types of athletes.[2,6,18]

The repetitive valgus stress applied to the medial elbow during baseball pitching, serving in tennis, or upper-extremity weight bearing may lead to microtrauma to the anterior bundle of the UCL. Over time, this microtrauma is thought to negatively affect the structural integrity of the tissue, leading to ligamentous insufficiency. An acute overload moment may cause rupturing of the worn ligament, which may be felt or heard as a pop. Throwing athletes with significant insufficiency or complete rupture of the anterior bundle of the UCL are typically unable to continue to throw and often require surgical intervention.[13,16] A successful return to sport has been reported in 85% to 95% of patients after UCL reconstruction, but rehabilitation is strenuous and generally requires more than 12 months.[5,15,17,22]

There are indications that the type and location of UCL injury to the anterior bundle are clinically relevant. For example, it has been suggested that distal tears of the anterior bundle may be less amenable to nonoperative management than proximal tears in professional pitchers.[9,10] Furthermore, primary repair of the anterior bundle rather than reconstruction may be a viable option in younger athletes with localized or acute distal or proximal tears, as the lower levels of chronic attritional stress may have preserved a better structural integrity of the remainder of the ligament.[19,21]

The main purpose of this study was to increase our understanding of the pathoanatomy of injury to the UCL by performing a descriptive analysis of the surgical inspection of the anterior bundle in a single-surgeon cohort of patients who underwent UCL reconstruction. We hypothesized that UCL injuries would be a heterogeneous entity, manifesting in various configurations of chronic and acute tissue damage. Our secondary goal was to examine the association between demographic and clinical characteristics and the types of pathoanatomy observed during surgery.

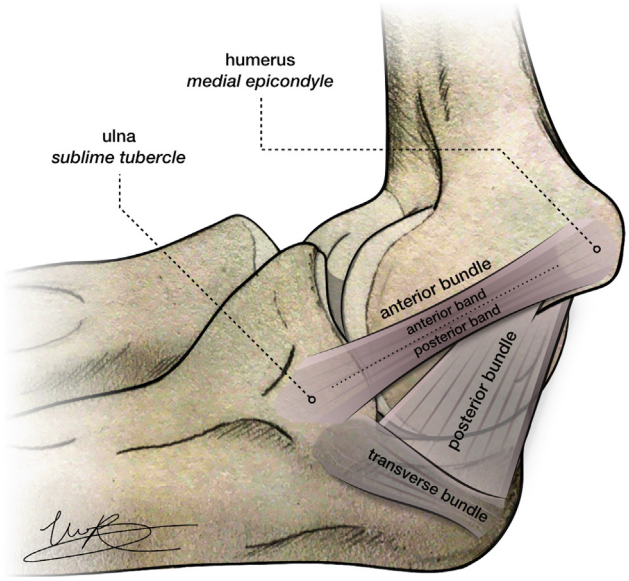

Figure 1 Anatomy of medial ulnar collateral ligament: anterior bundle (connecting the anteroinferior medial epicondyle of the humerus and sublime tubercle of the ulna and subdivided into anterior and posterior bands), posterior bundle, and transverse bundle.

Materials and methods

This is a retrospective review of a single surgeon's intraoperative evaluation of 163 anterior bundles of the UCL during surgical reconstruction. The medical records and operative reports of patients undergoing UCL reconstruction from 2009 to 2017 performed by the senior author (L.S.O.) at our institution were analyzed. The multi-institutional Research Patients Data Registry was searched using Current Procedural Terminology codes (24345 and 24246) to collect the data of patients who underwent UCL reconstruction. The senior author performed 176 UCL reconstructions. Of 176 patients, 163 (94%) had operative reports containing an explicit description of the observed injury to the anterior bundle of the UCL available for review and were included for analysis. All medical records and operative notes were reviewed and assessed by the first author (R.J.M.) and last author (L.S.O.) using the Electronic Medical Record system (QPID Health, Boston, MA, USA).

During surgery, the flexor pronator muscle mass was elevated from the anterior bundle of the UCL, exposing the ligament for inspection. The undersurface of the anterior bundle was examined after longitudinal incision at the equator of the anterior bundle (between the anterior and posterior bands). Tear descriptions and observations of attenuation, perforation (focal hole within tissue), ossification and calcifications, and scar tissue formation, as well as the location and extent of these injury manifestations, were obtained from the operative reports (Table I).

Demographic characteristics were obtained from the medical records, including sex, age, race, type of sport, level of play, hand dominance, side of injury, cause of injury, onset of injury, occurrence of a pop during the initial injury, time between the

Table I Characteristics of pathoanatomy

Tear (yes or no)
Location
Description
Scar tissue formation (yes or no)
Location
Attenuation (yes or no)
Location
Tissue perforation (yes or no)
Location
Ossification or calcifications (yes or no)
Description

initial injury and surgery, history of significant ipsilateral elbow or shoulder injury or surgery, and prior arthroscopic removal of posteromedial osteophytes. Available magnetic resonance imaging (MRI) data (1.5 or 3.0 T) were evaluated using the Picture Archiving and Communications system (GE Centricity System workstation, version 2.1; GE Healthcare Systems, Chalfont St Giles, UK) and reviewed to assess whether the presence and location of tissue disruptions matched the MRI findings.

Statistical analysis

Data were described using frequencies and percentages for dichotomous and categorical variables, means and standard deviations for normally distributed continuous data, and medians and interquartile ranges for nonparametric continuous data. Data comparisons were performed using the Fisher exact test for binary and categorical outcome variables and the Kruskal-Wallis test for nonparametric continuous outcome variables. *P* values were adjusted for multiple comparisons using the false discovery rate correction.[1] Post hoc pair-wise comparisons were performed using the Fisher exact test with Bonferroni correction.

Statistical analysis was performed using STATA/SE statistical software (version 14.2; StataCorp, College Station, TX, USA). False discovery rate–adjusted *P* values less than .05 were considered statistically significant.

Results

Demographic characteristics

The demographic characteristics of the patients included in this study are summarized in Tables II and III. The study population consisted predominantly of white, male, high school or collegiate baseball pitchers. MRI data were available for review in 153 of 163 patients (94%), of whom 93 patients (61%) underwent magnetic resonance arthrography.

Table II Demographic characteristics

	Cohort (N = 163)
Male, n (%)	158 (97)
Age, median (IQR), yr	19.1 (2.6)
Time to surgery, median (IQR), weeks	11.7 (18.7)
Race, n (%)	
White	146 (90)
Hispanic	6 (3.7)
Asian	4 (2.5)
Other or unknown	7 (4.3)
Hand dominance, n (%)	
Left	28 (17)
Right	135 (83)
Cause of injury, n (%)	
Throwing	154 (94)
Hyperextension valgus trauma	5 (3.1)
Other	4 (2.5)
Onset of injury, n (%)	
Acute moment	106 (65)
Non-acute moment	54 (33)
Unknown	3 (1.8)
Popping sensation, n (%)	
Yes	48 (29)
No	115 (71)
History of ipsilateral elbow or shoulder surgery, n (%)	
Yes	41 (25)
Elbow	37 (90)
Shoulder	4 (10)
No	122 (75)
History of osteophyte removal, n (%)	
Yes	17 (10)
No	146 (90)

IQR, interquartile range.

UCL anterior bundle injury

Figure 2 shows the breakdown of injury manifestations observed in our sample. The main characteristic of the majority of UCL injuries was a single tissue disruption (65%, 106 of 163 patients; further distinguished into single tears and single perforations) or tissue disruptions at more than 1 location of the anterior bundle (23%, 37 of 163; further distinguished into tear and perforation combinations and multiple tears). The anterior bundles of the remaining 12% of patients (20 of 163) did not show distinct fiber tissue disruptions but were characterized by localized or generalized signs of chronic injury, such as attenuation (stretched out or loose with forceps), and were functionally incompetent (non-tear insufficiency).

Table IV summarizes the various injury characteristics of the anterior bundle in our study population and among the 5 subgroups. Tissue disruptions were located at the proximal attachment site, midsubstance, and distal attachment site of

Table III Sport and level of play

	Cohort (N = 163)
Sport, n (%)	
Baseball	152 (93)
Pitcher	132 (87)
Catcher	5 (3.3)
Other position	15 (9.9)
Javelin	5 (3.1)
Softball	2 (1.2)
Gymnastics	2 (1.2)
Football (quarterback)	1 (0.6)
Snowboarding	1 (0.6)
Level of play, n (%)	
High school	66 (40)
Collegiate	87 (53)
Professional	9 (5.5)
Recreational	1 (0.6)

the anterior bundle in 37% (53 of 143 patients), 9.1% (13 of 143), and 30% (43 of 143), respectively, and at both the proximal and distal attachment sites in 20% (28 of 143). Full-thickness perforations of the anterior bundle were observed in 19 patients, with these perforations being the main injury component in 8 patients. In the other 11 cases, both a perforation and a tear of the anterior bundle were observed. Among patients with 1 or more tissue disruptions of the anterior bundle, scar tissue formation at the location of the disruption was observed in 29% of patients (41 of 143). Of patients with tears and/or perforations, 56% (80 of 143) showed areas of attenuation and thinning of the anterior bundle; in the majority of these patients, the area of disruption or beyond was affected (67 of 80, 84%).

The anterior bundles of the subgroup of patients who did not show distinct fiber disruptions were predominantly defined by attenuation and thinning of the anterior bundles (19 of 20 patients, 95%). Ten of these patients were observed to have attenuation and thinning of the tissue fibers throughout the entire course of the anterior bundle (10 of 19, 53%).

Calcifications or loose bodies were observed in 6.1% of patients (10 of 163). In addition, 1 notable patient showed a complete tear at the midsubstance between 2 ossified regions of the anterior bundle and 1 patient showed a nearly completely ossified anterior bundle with only a very small portion of the proximal aspect of the ligament that was not ossified.

Comparison with MRI

The presence and location of tissue disruptions matched the MRI findings in 124 of 153 patients (81%). A complete match was found in 103 of 153 patients (67%), including 9 patients who appeared to have a UCL tear on MRI that was best described as a full-thickness perforation of the anterior bundle during surgical inspection. In 21 of 153 patients (14%), a tear was observed on both MRI and intraoperatively but additional tissue disruption of the anterior bundle was found during surgical inspection.

A mismatch between MRI and surgical inspection was found in 29 of 153 cases (19%). In the large majority of these cases (23 of 153 patients, 15%), a tear was observed on MRI whereas surgical inspection revealed attenuation, thinning, or degeneration rather than distinct fiber disruption.

Description of UCL anterior bundle tears

Table V provides an overview of the intraoperative descriptions of the distal, midsubstance, and proximal tears in our sample. Approximately 1 in 10 patients was observed to have a complete or nearly complete rupture of the anterior bundle (9.5%, 15 of 158). In addition, 52% of patients had a tear that was described as a full-thickness or near full-thickness rupture (52%, 82 of 158), indicating complete tissue disruption of part of the anterior bundle. A significant difference in anterior vs. posterior band involvement was found among partial tears at the distal vs. proximal attachment site of the anterior bundle ($P = .032$). Partial full-thickness tears at the distal attachment site mainly affected the anterior band of the anterior bundle, whereas tears located proximally predominantly involved the posterior band of the anterior bundle (Fig. 3).

Pathoanatomy and patient characteristics

Table VI shows the comparison of demographic and clinical characteristics among the subgroups of UCL injuries observed during surgery. The only demographic characteristic that showed a significant difference among the subgroups was the occurrence of a popping sensation at the time of injury ($P = .032$). A pop sign was more frequently experienced by patients with anterior bundle injuries characterized by a single tear compared with patients with non-tear insufficiency ($P = .030$).

Discussion

We examined the pathoanatomy of the anterior bundle of the UCL in a single-surgeon cohort of patients who underwent UCL reconstruction at our institution. We stratified injuries to the anterior bundle of the UCL into 5 subgroups based on tissue disruption patterns. The observed variety of configurations and signs of chronic attritional injury, including attenuation, scar tissue formation, and ossification, underscores the heterogeneity of injury to the anterior bundle of the UCL. The only clinical characteristic showing a significant difference among the subgroups was the occurrence of a popping sensation during the initial injury; this was more frequently experienced by patients with isolated single tears than patients with non-tear

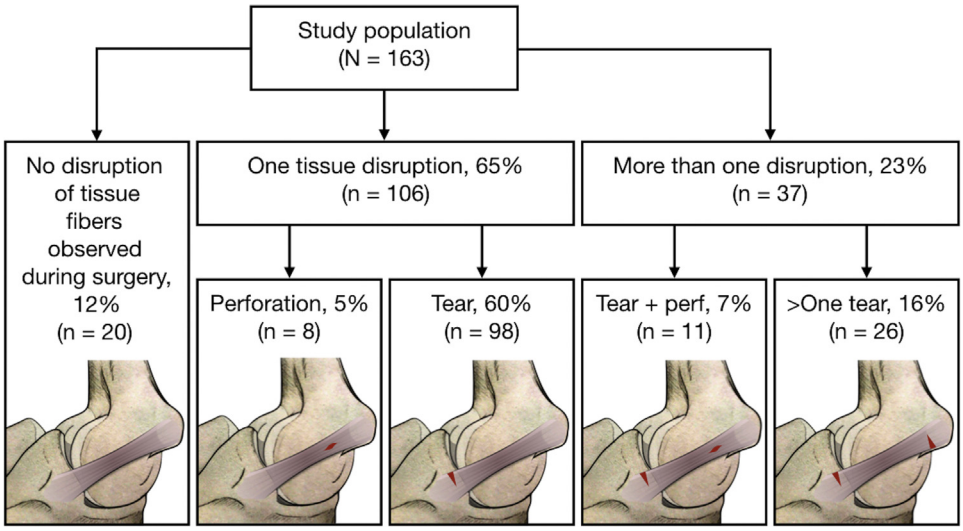

Figure 2 Breakdown of study population into 5 subgroups based on tissue disruption configuration. *perf*, perforation.

Table IV Injury characteristics of the anterior bundle of the ulnar collateral ligament in patients undergoing reconstruction

	Non-tear insufficiency, n = 20	Perforation, n = 8	Tear, n = 98	Tear and perforation, n = 11	>1 tear, n = 26	Total, N = 163
Tissue disruption, n (%)						
Distal	—	0 of 8	42 (43)	1 of 11	0	43 (26)
Midsubstance	—	2 of 8	11 (11)	0 of 11	0	13 (8.0)
Proximal	—	6 of 8	45 (46)	2 of 11	0	53 (33)
Distal and proximal	—	—	—	7 of 11	21 (81)	28 (17)
Other	—	—	—	1 of 11	5 (19)	6 (3.7)
NA	20 (100)	—	—	—	—	20 (12)
Scar tissue, n (%)	3 (15)	1 (13)	38 (39)	0	6 (23)	48 (29)
Generalized	1 of 3	0 of 1	4 (11)	—	2 of 6	7 (15)
At site of disruption	—	0 of 1	30 (79)	—	0 of 6	30 (63)
At site of disruption and other location	—	0 of 1	0	—	4 of 6	4 (8.3)
At other location than site of disruption	—	1 of 1	4 (11)	—	0 of 6	5 (10)
Localized (without tissue disruption)	2 of 3	—	—	—	—	2 (4.2)
Attenuation, n (%)	19 (95)	5 (63)	51 (52)	9 (82)	15 (58)	99 (61)
Generalized	10 (53)	0 of 5	9 (18)	1 of 9	4 (27)	24 (24)
At site of disruption	—	3 of 5	28 (55)	2 of 9	10 (67)	43 (43)
At site of disruption and other location	—	0 of 5	4 (7.8)	5 of 9	1 (6.7)	10 (10)
At other location than site of disruption	—	2 of 5	10 (20)	1 of 9	0	13 (13)
Localized (without tissue disruption)	9 (47)	—	—	—	—	9 (9.1)
Ossification or calcifications, n (%)	1 (5.0)	0	10 (10)	0	1 (3.9)	12 (7.4)
Calcifications	0 of 1	—	3 of 10	—	0 of 1	3 (25)
Ossicle or loose body	0 of 1	—	6 of 10	—	1 of 1	7 (58)
Ossification of ligament	1 of 1	—	1 of 10	—	0 of 1	2 (17)

NA, not applicable.

Table V Description of tears of anterior bundle of ulnar collateral ligament observed during surgery

	Distal tears, n = 70	Midsubstance tears, n = 15	Proximal tears, n = 73
Tear description, n (%)*			
High-grade partial tear	12 (17)	1 (6.7)	13 (18)
Peeled off	3 (4.3)	0	2 (2.7)
Partial avulsion off of bone	9 (13)	0	1 (1.4)
Full-thickness or near full-thickness tear	32 (46)	12 (80)	38 (52)
Crescent full-thickness tear	1 (1.4)	0	1 (1.4)
Periosteal sleeve avulsion–type tear	4 (5.7)	0	0
Complete or near complete rupture	6 (8.6)	1 (6.7)	8 (11)
Undefined tear	3 (4.3)	1 (6.7)	7 (9.6)
Other	0	0	3 (4.1)

* The data of 1 patient, showing a complex delaminated rupture involving the proximal, midsubstance, and distal attachment sites, were not included in this table.

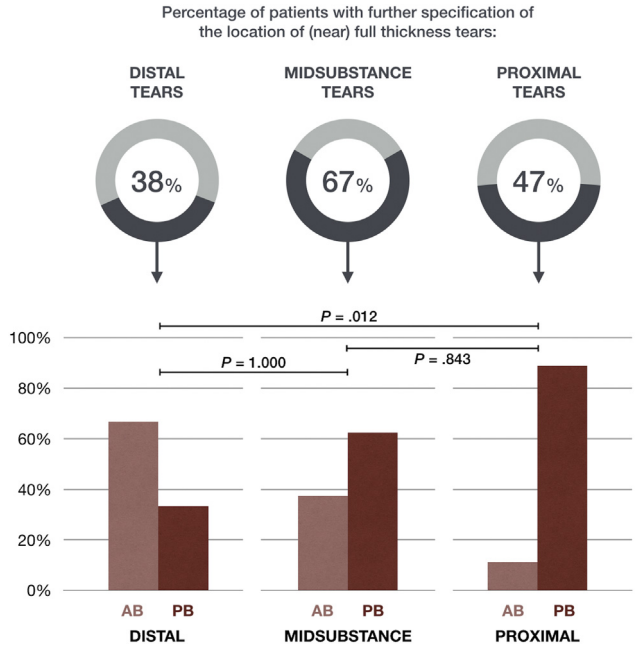

Figure 3 Bar charts showing a significant difference in the proportion of anterior band (*AB*) and posterior band (*PB*) involvement in distal and proximal full-thickness and near full-thickness tears of the anterior bundle of the ulnar collateral ligament.

insufficiency of the anterior bundle ($P = .030$). Furthermore, partial full-thickness tears at the distal attachment site disproportionately affected the anterior band of the anterior bundle, whereas partial tears at the proximal attachment site mainly affected the posterior band ($P = .012$).

The large majority of patients showed 1 or more tissue disruptions of the anterior bundle of the UCL (143 of 163 patients, 88%), with an evenly balanced prevalence of proximal and distal tears (46% vs. 44%). We observed a variety of manifestations of chronic attritional injury to the anterior bundle, including areas of attenuation, scar tissue formation, and calcifications and ossification, subscribing the general assumption that UCL injuries in throwers are etiologically acute-on-chronic injuries.[3,6,7,11,18,20] Distal tears were typically characterized by peeling off or stripping of the undersurface of the anterior bundle from the sublime tubercle. We might speculate that in more severe cases, this avulsion process led to complete detachment of the tissue fibers from the sublime tubercle, resulting in high-grade partial, full-thickness, or complete distal UCL tears. Proximal tears appeared more parallel to the attachment site of the anterior bundle at the medial epicondyle, resulting in more generalized weakening of the proximal tissue fibers (high-grade partial tears) and eventual partial or complete disruption at the proximal attachment site.

Comparison of tear presence and location on MRI shows that what appears to be a tear on MRI may in fact be a perforation of anterior bundle fibers on surgical inspection in a number of cases. Furthermore, what appears to be a low-grade tear on MRI may be an area of attenuation or thinning rather than a distinct fiber disruption. Overall, the presence and localization of tissue disruptions on MRI were found to closely match tissue disruptions as observed during surgery. With increasing quality of MRI, future prospective studies may be able to assess the level of accuracy for detection of more subtle signs of injury to the anterior bundle.

The majority of tears in our sample were partial ruptures, defined as full-thickness or near full-thickness tears. Our findings suggest that the anterior band of the anterior bundle is more vulnerable in distal tears whereas the posterior band is more frequently affected in proximal tears ($P = .012$). This difference may be related to differences in anatomy and strain patterns of the anterior and posterior bands of the anterior bundle through full elbow range of motion. Jackson et al[12] examined the biomechanics of different parts of the UCL and found an isometric strain pattern of the anterior band through elbow range of motion, whereas the strain on the posterior band increased from a level below that of the anterior band at lower flexion angles to a level above that of the anterior band at higher flexion

Table VI Comparison of demographic and clinical characteristics among subgroups of ulnar collateral ligament injuries

	Non-tear insufficiency, n = 20	Perforation, n = 8	Tear, n = 98	Tear and perforation, n = 11	>1 tear, n = 26	*P* value* (unadjusted *P* value)
Age, median (IQR), yr	18.9 (3.3)	20.0 (2.8)	19.0 (2.2)	20.4 (3.4)	19.2 (2.8)	.532 (.456)
Time to surgery, median (IQR), weeks	15.1 (62.8)	17.1 (32.8)	10.9 (23.7)	11.6 (11.0)	12.1 (9.4)	.546 (.546)
Acute moment, n (%)†	9 (47)	4 (50)	69 (71)	8 (73)	16 (64)	.354 (.253)
Popping sensation, n (%)	1 (5.0)	2 (25)	38 (39)	1 (9.1)	6 (23)	.032 (.009)
Previous shoulder or elbow injury, n (%)	10 (50)	0	24 (24)	1 (9.1)	6 (23)	.089 (.038)
History of osteophyte removal, n (%)	5 (25)	0	9 (9.2)	0	3 (12)	.354 (.214)

IQR, interquartile range.
* *P* values were adjusted for multiple comparisons using the false discovery rate correction.
† Onset of injury could not be obtained from the medical records of 3 patients (1.8%, 3 of 163 patients).

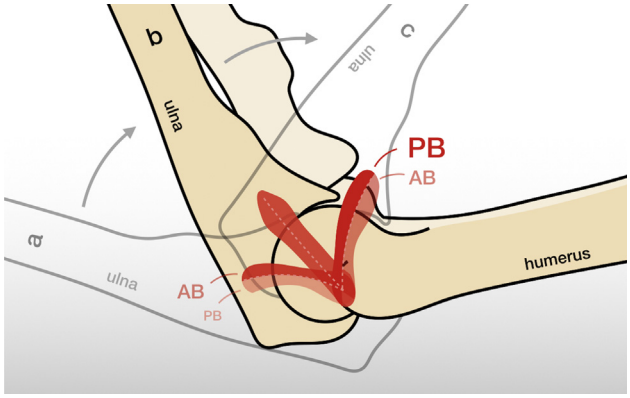

Figure 4 Levels of highest tissue stress transfer from the anterior band (*AB*) of the anterior bundle in elbow extension (*a*) to the posterior band (*PB*) of the anterior bundle of the ulnar collateral ligament in elbow flexion (*c*). Equal stress on the AB and PB has been observed at approximately 90° of flexion (*b*).

angles (Fig. 4). In addition, Yoshida et al[23] performed an ultrasound study and described significant anatomic differences in inclination angles of the anterior and posterior bands of the anterior bundle at the distal attachment to the sublime tubercle of the ulna, which may be related to the difference in pathoanatomy at the distal and proximal attachment sites observed in our study as well. The exact reasons for the observed difference in anterior band and posterior band involvement in proximal and distal tears remain to be elucidated in future research.

A popping sensation was reported by one-third of patients in our sample, with the highest incidence among patients showing single tears (39%). An interesting finding was that 1 patient with a non-tear insufficiency injury reported a pop during the initial injury as well. A possible explanation for this finding is that there may have been an acute disruption of more centrally located, encapsulated tissue fibers that could not be observed on the outside of the ligament during direct inspection and was not revealed after longitudinal incision of the ligament. Future studies may focus on identification of these ''covert'' fiber disruptions with advanced imaging methods in patients with UCL insufficiency. The popping sensation in patients with UCL injury has not yet been addressed in the current literature, and future studies are needed to elucidate the diagnostic value of the salient finding of a pop sign in patients in whom UCL injury is clinically suspected.

Several limitations must be considered when interpreting our findings. First, the retrospective nature of this study needs to be considered. We analyzed a large single-surgeon series of patients who underwent UCL reconstruction at our institution. Other surgeons may use different terminology or observe other injury details, which may limit the generalizability of our findings. A prospective design with a standard method to characterize UCL injury patterns may improve the accuracy and reliability of similar observations in future research. That being said, the observations by a single experienced surgeon enhanced consistency in terminology, allowing the observation of patterns in the data that are attributable to differences among patients rather than errors related to differences in the use of terminology. Because of the limitations of our retrospective design, future studies are needed to verify the findings of our secondary analyses and provide higher-level evidence for the associations observed. A second limitation is the possible under-reporting of more subtle signs of attritional chronic injury in patients with other more apparent injury to the anterior bundle, such as a complete or extensive full-thickness rupture. Nevertheless, a high prevalence of signs of chronic injury and multifocality of injury was observed in our study. A third limitation is the predominance of throwing athletes in our sample. This limits our findings to throwing-related UCL injuries, which may not reflect the pathoanatomy of valgus-hyperextension UCL injuries in other sports, such as wrestling and judo. However, we believe that our study provides a comprehensive overview of the various appearances of injury to the anterior bundle

of the UCL. Considering these limitations, this is the first attempt to describe the pathoanatomy of UCL injury currently available in the literature. An avenue for future research is to further investigate the correlation of preoperative imaging to the various manifestations of injury to the anterior bundle of the UCL.

Conclusion

This study shows the heterogeneity of injury to the anterior bundle of the UCL, with the majority of patients showing 1 or more tissue disruptions of the anterior bundle and a high prevalence of attritional chronic injury. Patients with isolated single tears more frequently experienced a pop sign than patients with non-tear insufficiency injury to the UCL. We observed a difference in anterior band and posterior band involvement in proximal and distal tears, with distal tears more frequently affecting the anterior band and proximal tears more frequently affecting the posterior band. The findings of this study contribute to our understanding of the pathoanatomy of the UCL and may guide sample selections in future research.

Disclaimer

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