Arthroscopic assessment for lateral collateral ligament complex deficiency of the elbow: a cadaveric study

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ORIGINAL PAPER

Arthroscopic assessment for lateral collateral ligament complex deficiency of the elbow: a cadaveric study

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Abstract

Purpose To evaluate whether elbow instability due to lateral collateral ligament complex injury can be assessed reliably through arthroscopy.

Methods Eight fresh human cadaveric elbows were placed in a simulated lateral decubitus position. The radiocapitellar joint (RCJ) gap and ulnohumeral joint (UHJ) gap (mm) were measured with different sizes of probes from the posterolateral viewing portal. The elbow was 90 degrees flexed with neutral forearm rotation for RCJ gap measurement and 30 degrees flexed with full supination for UHJ gap measurement. Sequential testing was performed from Stage 0 to Stage 3 (Stage 0: intact; Stage 1: the release of the anterior 1/3 LCL complex; Stage 2: the release of the anterior two thirds of the LCL complex; and Stage 3: the release of the entire LCL complex) on each specimen. The mean gap of RCJ and lateral UHJ was used for the comparison between stages with the intact elbow.

Results The mean RCJ gap distance in Stage 2 and Stage 3 was significantly increased compared to that in Stage 0 (Stage 0 vs. Stage 2: $P = .008$; Stage 0 vs. Stage 3: $P = .012$). The mean UHJ gap distance of Stage 1, Stage 2, and Stage 3 was significantly increased compared to that in Stage 0 (Stage 0 vs. Stage 1: $P = 0.025$; Stage 0 vs. Stage 2: $P = .010$; Stage 0 vs. Stage 3: $P = .011$). In contrast, the release of the anterior 1/3 of the LCL complex (Stage 1) was not significantly increased compared to the mean joint gap distance of RCJ ($P = .157$).

Conclusion Arthroscopic measurement of joint gap widening in RCJ and UHJ is a reliable assessment method to detect LCL complex deficiency that involves the anterior two thirds or more.

Keywords Lateral collateral ligament · Elbow · Varus laxity · Diagnostic arthroscopy · Arthroscopic assessment · Posterolateral rotatory instability · Lateral epicondylitis · Tennis elbow · Elbow instability

Introduction

Elbow arthroscopy has evolved and is now accepted as a commonly used technique in the diagnosis and treatment of intra-articular elbow pathology of the intra-articular fracture of the radial head and coronoid, arthritis, and lateral epicondylitis (LE) [1–7]. Acute trauma has been also widely managed using arthroscopic techniques [8, 9]. However, lateral collateral ligament (LCL) complex injury [6], including the lateral ulnar collateral ligament (LUCL) cannot

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always be precisely assessed through physical examination or radiography due to muscle guarding, pain, and excessive joint fluid with intra-articular bleeding. In the surgical management for other lateral pathology, arthroscopic extensor carpi radialis brevis (ECRB) release for the treatment of chronic LE also has been widely performed with favourable clinical outcomes. Yet, elbow instability, especially posterolateral rotatory instability (PLRI), has been reported concurrently in refractory LE [10–12]. For this reason, undiscovered concomitant LCL complex injury can be missed during arthroscopic procedures. However, arthroscopic assessments for discovering the LCL complex deficiency are still out of consensus until now.

This study aimed to (1) determine whether elbow instability, as evidenced by the widening of the radiocapitellar joint (RCJ) and ulnohumeral joint (UHJ) space, can be assessed reliably using arthroscopy and (2) determine whether arthroscopic assessment can distinguish between the intact elbow and cases with mild or severe instability due to LCL complex injury. Elbow instability due to lateral collateral ligament complex injury could be assessed reliably through arthroscopy.

Materials and methods

Eight fresh-frozen unpaired cadaveric upper limbs (five right and three left limbs) from the fingertip to the mid-humerus were thawed at room temperature overnight (average age, 73 ± 11 years). The number of specimens was chosen on the basis of the availability of cadavers at our institution and the adequacy of this anatomical study. Any specimen with ligament insufficiency that can be detected by performing either the posterolateral rotatory drawer test or the varus stress test under pre-experimental c-arm was excluded. Any specimen with an obvious bony deformity that limits the range of motion was also excluded. The common flexor and extensor humeral origins were preserved. For the purpose of this experiment, the LCL, the annular ligament, and the lateral capsule were treated as a single unit we refer to as the LCL complex.

Experimental setup

Each cadaveric elbow was mounted in a simulated lateral decubitus position with a vise attached to the humeral shaft (Fig. 1A). The elbow was in 90-degree flexion and neutral forearm rotation in the experimental setting. A 4-mm 30-degree arthroscope (IM4000, IM4120; ConMed Linvatec, Utica, NY, USA) was used for the experiment. Four different-sized customized probes were used for the measurement of the joint gap (Fig. 1B). Custom-made probes are created by bending a long spinal needle with a gauge of 18 or higher to the desired length, and then grinding the tip to make it blunt using tools like a grinder.

Arthroscopic measurement of the joint gap

The RCJ and UHJ were visualized from the posterolateral viewing portal (Fig. 2). The joint gap was measured under 30-degree flexion with external rotation (supination) of the forearm (posterolateral stress position) using a custom-made probe (2, 3, 4, and 5 mm) that was inserted from a soft spot portal (Fig. 1B). Under the posterolateral stress position, the measurement tool was positioned on the bare area of olecranon in ulnohumeral joint. The measurement was conducted using four different sized probe. Then, the probe was moved to radiocapitellar joint. The probe was positioned on the centre of radiocapitellar joint.

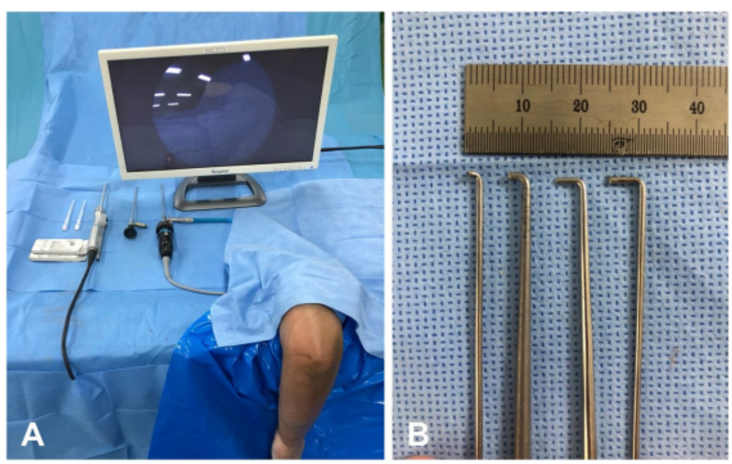

Fig. 1 Experimental setup for the cadaveric arthroscopic study. A. The elbows were placed in a simulated lateral decubitus position. B. Four different-sized customized probes (2, 3, 4, and 5 mm) were used for the measurement of the joint gap

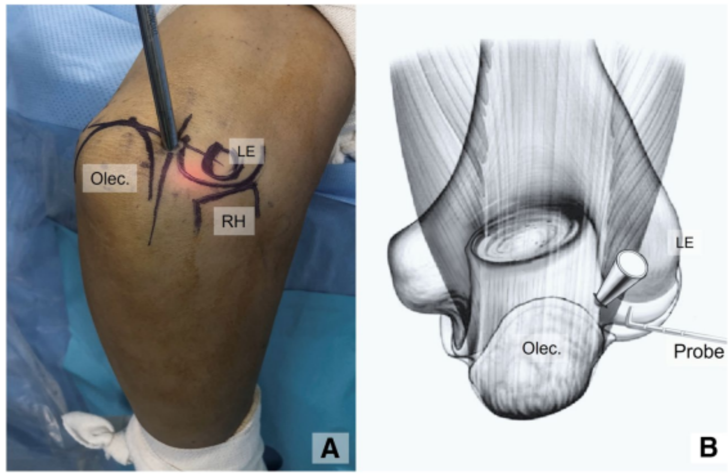

Fig. 2 Posterolateral portal for viewing of posterolateral ulnohumeral joint and posterior radiocapitellar joint. A. surface anatomy for marking the posterolateral portal; crossing point between the transverse line (just above from olecranon tip) and longitudinal line (just lateral to lateral border of olecranon) B. Arthroscope follow the lateral border of olecranon and touching the radial head. Arthroscopic probe as the measurement tool is inserted through the soft spot that is parallel to radiocapitellar joint

Arthroscopic sequential injury model

The LCL complex was divided into three parts (anterior, middle, and posterior) based on the diameter of the radial head. For the precise measurement of the diameter, the subcutaneous layer with skin was dissected until the extensor tendon layer was exposed. The overlying common extensor tendon was preserved with the LCL complex. To calculate each cut of the LCL complex, the anterior–posterior diameter of the radial head was measured with a digital caliper (with the forearm in neutral rotation) and divided into thirds using a spinal needle (Fig. 3A). The needle was inserted through the RCJ from the lateral side. The needle was placed into the intra-articular space that was confirmed with arthroscopy from the anteromedial viewing portal (Fig. 3B). The first needle was inserted on the anterior edge of the radial head. The second needle was on the point of the anterior one-third of the radial head (Fig. 4A). The third needle marked the point of the anterior two-thirds, and the fourth needle was on the point at which the posterior edge of the radial head was positioned. The second and third spinal needles were the landmark indicating where to stop the arthroscopic release for Stage 1 and Stage 2 (Fig. 4B). The LCL complex was cut arthroscopically in three stages: (1) the anterior one-third of the LCL (Stage 1), (2) the anterior two-thirds of the LCL (Stage 2), and (3) the entire LCL (Stage 3). The overlying common extensor tendon was preserved from the LCL complex.

Sequential measurement of the joint gap was performed from Stage 0 to Stage 3 (Stage 0: intact; Stage 1: the release of the anterior one third of the LCL complex; Stage 2: the release of the anterior two thirds of the LCL complex; and Stage 3: the

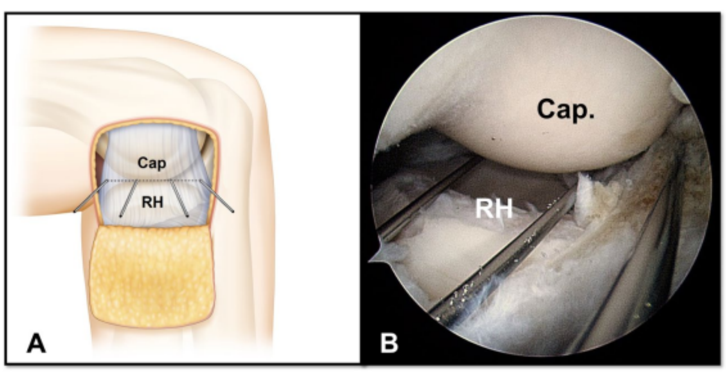

Fig. 3 The LCL was divided into three parts (anterior, middle, and posterior) based on the diameter of the radial head. A. After measuring the diameter of the radial head, far anterior and posterior spinal needles were inserted. Two other spinal needles were placed at the point that divides the diameter of the radial head into three parts. B. A needle was inserted through the radiocapitellar joint from the lateral side. The needle that was placed into the intra-articular space was confirmed with arthroscopy from the anteromedial viewing portal

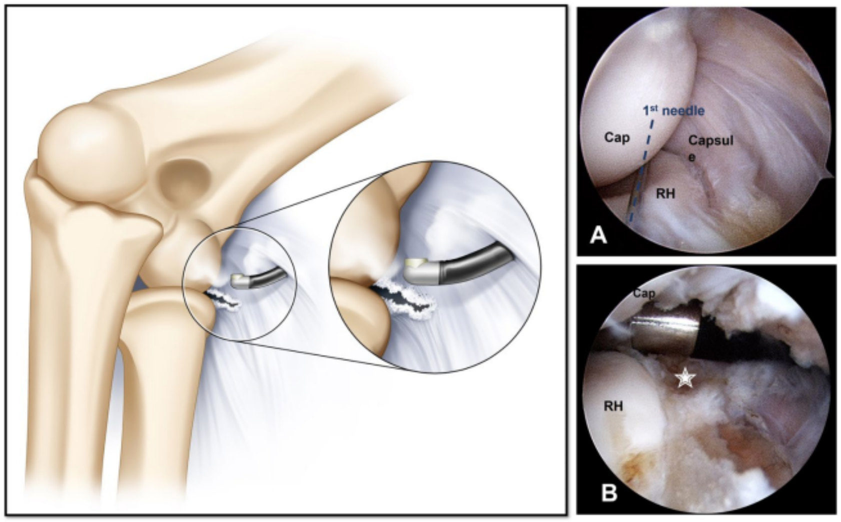

Fig. 4 Arthroscopic sequential injury model of the LCL complex. The release of the LCL complex was performed using the electrocautery device from the intra-articular space. A. Serial cutting of the LCL complex was done using a spinal needle as guidance for each stage. B. Since the LCL complex was attached closely with the lateral capsule, the release was conducted including the lateral capsule (star; capsule–ligament complex)

release of the entire LCL complex) on each specimen. Joint gap measurement was performed in the posterolateral stress position when the release was finished in each stage after the measurement of the normal joint gap (Stage 0). Two orthopaedic surgeons performed the measurement which was blinded to each other's measurement. While Measurement 1 is conducting measurements, the other measurer remains outside the laboratory. Once Measurement 1 completes the experiment, Measurement 2 enters the laboratory and performs the same measurements in the same manner. In the subsequent sets, measurements are taken alternately in this manner. The measured values are shared only after all experiments are finished, so the measurers are unaware of each other's measurements. The mean gap of the RCJ and lateral UHJ was used for the comparison between stages with the elbow intact. The measurements were obtained with the agreement of two orthopaedic surgeons (J.-M.K., E.K.).

Statistical analysis

The data for Stages 1–3 were compared with the data collected for the intact elbow (Stage 0) for each angle of elbow flexion evaluated. The data were modeled using the analysis of variance (ANOVA). All data were analyzed using the one- or two-factor repeated-measures ANOVA test with post hoc comparisons. *P*-values of < 0.05 were considered statistically significant. According to our power analysis, with a sample size of $n = 8$, we had at least an 80% chance of detecting a statistical significance of 1.0 standard deviations between our experimental groups at $P < 0.05$. Statistical analyses were performed using SPSS version 12 (IBM, Armonk, NY, USA). The Friedman test with Bonferroni correction was used for comparisons. Power calculations were performed using G*Power, Version 3.1 (Heinrich Heine Universität Düsseldorf, Germany). The intraclass correlation coefficient with a confidence interval of 95% was employed to test the reliability of the measurement of joint gap (RCJ and UHJ) among two observers. Interpretation of the ICC was performed as described by Landis and Koch in 1977 [13]. The ICC reported a value between 0.0 and 1.0, as follows: 0.01 to 0.20 for slight agreement; 0.21 to 0.40 for fair agreement; 0.41 to 0.60 for moderate agreement; 0.61 to 0.80 for substantial agreement; 0.81 to 0.99 for almost perfect agreement; and 1.00 for perfect agreement.

Results

RCJ gap widening

The RCJ space increased progressively with the sequential cutting of the LCL-complex ($p < 0.001$) (Table 1, Fig. 5). Post hoc pairwise comparisons of the RCJ space between the intact model (Stage 0) and each stage of sequential cutting of the LCL-complex (Stages 1–3) demonstrated that the mean RCJ gap distance of Stage 2 and Stage 3 was significantly increased compared to that in Stage 0. In contrast, the release of the anterior 1/3 of the LCL complex (Stage 1) did not significantly increase the mean joint gap distance of the RCJ. (Stage 0 vs. Stage 1: $P = 0.157$; Stage 0 vs. Stage 2: $P = 0.008$; Stage 0 vs. Stage 3: $P = 0.010$). In Stage 3, the anterior radial head margin was observed during the examination in all specimens (Fig. 7A, Video 1).

Table 1 Comparison with Intact (Stage 0) Radio-capitellar joint widening

		Mean	SD	Min	Max	*P*-value
Stage 0—Stage 1	Stage 0	2.5	0.76	2	4	0.157
	Stage 1	2.75	0.71	2	4	
Stage 0—Stage 2	Stage 0	2.5	0.76	2	4	0.008*
	Stage 2	3.75	0.89	3	5	
Stage 0—Stage 3	Stage 0	2.5	0.76	2	4	0.010*
	Stage 3	5.6	0.52	5	6	

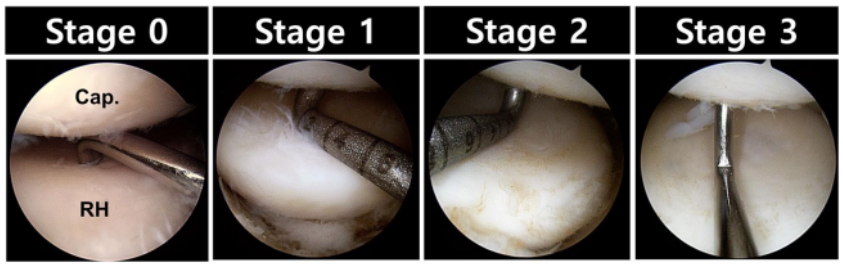

Fig. 5 The mean RCJ gap distance of Stage 2 and Stage 3 was significantly increased compared to that of Stage 0 (Stage 0 vs. Stage 2: $P=0.008$; Stage 0 vs. Stage 3: $P=0.010$)

Table 2 Comparison with Intact (Stage 0) Ulno-humeral joint widening

		Mean	SD	Min	Max	*P*-value
Stage 0—Stage 1	Stage 0	2.38	0.74	2	4	0.025*
	Stage 1	3	0.76	2	4	
Stage 0—Stage 2	Stage 0	2.38	0.74	2	4	0.010*
	Stage 2	4.25	1.04	3	6	
Stage 0—Stage 3	Stage 0	2.38	0.74	2	4	0.011*
	Stage 3	5.5	0.76	4	6	

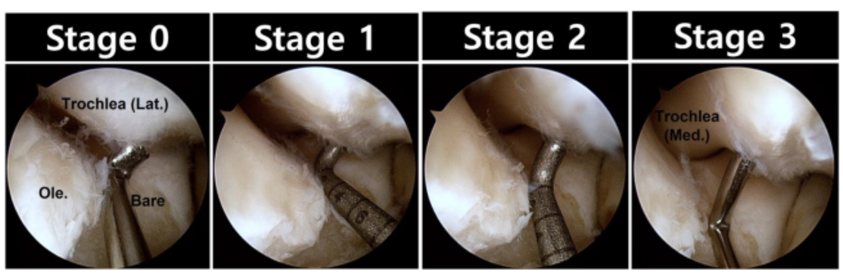

Fig. 6 The mean UHJ gap distance of Stage 1, Stage 2, and Stage 3 was significantly increased compared to that of Stage 0 (Stage 0 vs. Stage 1: $P=0.025$; Stage 0 vs. Stage 2: $P=0.010$; Stage 0 vs. Stage 3: $P=0.011$)

UHJ gap widening

The mean UHJ gap distance of Stage 1, Stage 2, and Stage 3 was significantly increased compared to that of Stage 0 (Table 2, Fig. 6). The release of the anterior 1/3 of the LCL complex (Stage 1) did not significantly increase the mean joint gap distance of the RCJ (Stage 0 vs. Stage 1: $P=0.025$; Stage 0 vs. Stage 2: $P=0.010$; Stage 0 vs. Stage 3: $P=0.011$). The medial trochlea was observed in all three stages of the examination (Fig. 7B, Video 2).

Post hoc *power analysis*

A post hoc power analysis revealed that with our sample size of $n=8$, our chance of detecting a statistically significant difference between the experimental groups at $P<0.05$ was 82% in all the comparisons shown, with exception of Stage 0 vs. Stage 1.

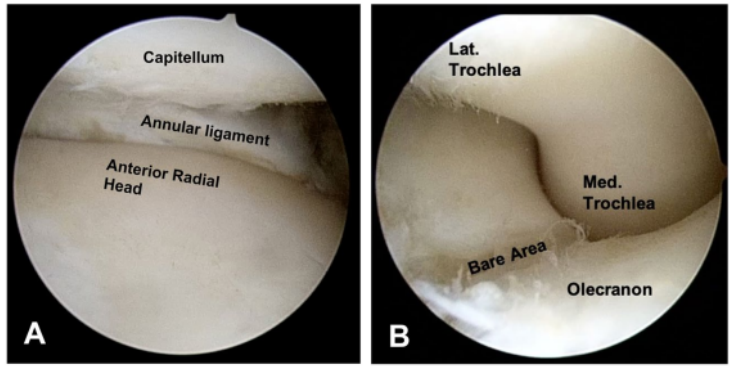

Fig. 7 A. Sunset sign. Because of the posterolateral subluxation of the radial head in Stage 3, the anterior border of the radial head can be observed from the posterolateral viewing portal using a 30-degree scope B. The "medial trochlea" sign is typically oriented in UHJ laxity. Since the trochlea cannot be observed unless the UHJ is subluxated, the medial trochlea sign is pathognomonic for end-stage LCL injury

Table 3 Interobserver reliability

	ICC	Category
Radiocapitellar joint	0.973 (95% CI, 0.941–0.987)	Almost perfect
Ulnohhumeral joint	0.954 (95% CI, 0.906–0.978)	Almost perfect

Inter-observer reliability

The interobserver reliability of both measurement of joint (RHJ/UHJ) among two independent observers, which was evaluated using the ICC, revealed almost perfect results (Table 3, ICC 0.973 for RCJ, ICC 0.954 for UHJ).

Discussion

Elbow arthroscopy has been used widely with the expanding role for the surgical management of elbow disease and trauma [1, 2, 14]. Since the LCL is the primary stabilizer of the elbow, it should be preserved or restored during the surgical procedure [15–17]. Therefore, dynamic fluoroscopic examination has traditionally been used as the imaging modality of choice to determine elbow laxity [18–22]. However, because of certain limitations in acute trauma, it was recommended to perform under anaesthesia for the management of the pain caused by the traumatic condition and because an additional c-arm setting that prolongs the surgery is required. The present study shows that LCL injury can be reliably assessed using arthroscopy to measure the RCJ and UHJ space with posterolateral rotatory stress. Arthroscopic assessment enables experts to assess elbow laxity before and after the procedure so that the surgeon could have a lower chance of missing an LCL injury and to make sure that the instability is corrected after the surgical repair of the LCL complex. While previous cadaveric studies have reported elbow laxity after the sequential cutting of the LCLs [18, 19], this is the first study to assess the validity and reliability of arthroscopic measurements of the elbow joint space to evaluate elbow instability or laxity. Further discussion should be followed for the clinical application in various surgical situations.

First, in the design of the study, three-staged LCL complex injury models were made, and those were compared with normal LCL complex as a control group. The joint gap widening was significantly increased from Stage 2 compared with that from Stage 0. There was no significant difference between Stage 0 and Stage 1 in both RCJ and UHJ. It can be translated that arthroscopic assessment is not able to detect the laxity in Stage 1 since anterior one-third deficiency of the LCL does not increase joint gap widening that is measured using arthroscopic measurement tools (different-sized probe: 2, 3, 4, and 5 mm). Second, the measurement was performed under the posterolateral rotatory stress position that 30 degrees of extension with full supination of the forearm for mimicking posterolateral rotatory stress. Since 90 degrees of elbow flexion puts the limb in a stable position, the assessment can miss the underlying laxity or instability if the examiner performed under the 90 degrees of flexion with the neutral forearm position, which is the elbow position under the lateral position of elbow arthroscopy. Third, specific arthroscopic findings (sunset sign and medial trochlea sign) were observed in all Stage 3. End-stage LCL injury (Stage 3) is anatomically involved in the LUCL and produces lateral rotatory instability. In the radiographic assessment under posterolateral rotatory stress, it was presented that the UHJ was subluxated posterolaterally and the radial head also followed in the same direction [21, 22]. We observed how this subluxation was presented arthroscopically. Because of the posterolateral subluxation of the radial head in Stage 3, the anterior border of the radial head can be observed from the posterolateral viewing portal with a 30-degree scope (Video 1: Sunset sign). In contrast, the sign was not found in Stage 1 and Stage 2 of the LCL-deficient elbow. Arthroscopic findings in the LUCL injury were previously described as the "elbow drive thru" sign that was originally described in shoulder arthroscopy. However, the driver thru sign was introduced under the direct soft spot portal so that the arthroscope (usually 4.5 mm in diameter) can go through the RCJ. However, the posterolateral viewing port with a soft spot working portal enables the simultaneous measurement of the joint gap widening in the RCJ and UHJ. The "medial trochlea" sign is typically oriented in UHJ laxity. Since the trochlea cannot be observed unless the UHJ was subluxated, the medial trochlea sign is specific for end-stage LCL injury (Video 2. Medial trochlea sign).

In any ligament reconstructive procedure in order to compare pre- and post-reconstructive joint gap, we recommend performing an arthroscopic assessment before the procedure for having the reference joint gap to compare with the joint gap after the procedure. Unlike the radiographic assessment that is usually performed on the contralateral elbow for the purpose of referencing, a pre-procedural diagnostic assessment would be an essential step toward the arthroscopic assessment for the correct comparison. A possible clinical indication would include the procedure with the risk of injury of the LCL or the procedure for LCL repair.

Arthroscopic ECRB release has been widely performed for the surgical management of chronic LE with successful clinical outcomes [23, 24]. However, it would take the potential risk of injuring the LCL due to the anatomical adjoining of the ECRB with the anterior part of the LCL complex [11, 25]. According to the findings of this study, the deficiency of the anterior 2/3 of the LCL complex (Stage 2) did significantly increase the joint gap in the RCJ and UHJ. The surgeon could detect joint laxity using the arthroscopic assessment if the LCL complex was significantly injured during the procedure by comparing it with the joint gap that was measured before the procedure.

Arthroscopic LCL/LUCL repair can also be the best indication for arthroscopic assessment. PLRI of the elbow is a chronic condition that results from LCL complex injury [26]. The primary pathology is the discontinuity of the LCL complex, which is usually its avulsion from the lateral epicondyle [27, 28]. Arthroscopic or arthroscopic-assisted procedures have a surgical benefit with clear visualization around the epicondyle using a 70-degree arthroscope so that the surgeon can recognize the avulsion point on the epicondyle for the sure placement of the anchor [29, 30]. Arthroscopic assessment enables the surgeon to perform prompt surgical evaluations after the procedure by measuring the joint gap with comparisons of the gap measured before the procedure.

However, this assessment technique has several limitations. As a limitation of the experimental cadaveric study, surgeons should be cautious when extrapolating these results to clinical practice. Given that soft-tissue laxity in cadavers may be different from that in patients, it is possible that the absolute values of joint spaces in patients may be different from those presented here. Therefore, we recommend doing comparative measurements of joint gaps before and after the procedure aimed to address joint laxity and ligament injury including LCL complex repair, augmentation and reconstruction. Second, while the injury model affecting only the anterior one-third of the LCL complex (Stage 1) did not significantly increase the joint space, it is important to reiterate that all measurements were made at time 0. In our daily activity, the lateral elbow is prone to repetitive varus stresses, so it is possible for injuries affecting only the anterior one-third of the LCL complex at time 0 to theoretically progress to involve more of the LCL complex over time. Another limitation is that the arthroscopic measurement tool is only able to detect the difference by a discrete point (1 mm). It cannot detect laxity with joint micro-loosening less than 1 mm. Therefore, this technique requires customized probes that are not readily available.

Conclusion

Arthroscopic measurement of joint gap widening in RCJ and UHJ is a reliable assessment to detect LCL complex deficiencies that involve the anterior 2/3 or more.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00264-023-06046-8.

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Author contribution Conceptualization: (J Kwak), Data curation (J Kwak), Formal Analysis (J Kwak), Funding acquisition: (I Jeon, J Kwak), Investigation (I Jeon), Methodology (E Kholinne, J Kwak), Project administration (I Jeon) Resources (SJ Hwang, I Jeon), Software (E Kholinne), Supervision (SJ Hwang, I Jeon), Validation (SJ Hwang, E Kholinne), Visualization (J Kwak), Writing – original draft (J Kwak), Writing – review & editing (E Kholinne, I Jeon).

Data Availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethic approval This is a cadaveric study. AMC (Asan Medical Center) Ethics Committee has confirmed that no ethical approval is required.

Consent to participate Not applicable. (Cadaveric study).

Consent for publication Not applicable. (Cadaveric study).

Competing interests The authors declare no competing interests.

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