의학박사 학위논문

The Effect of Radial Collateral Ligament Plication on Varus Stability in a Sequential Injury Model of the Lateral Elbow: A Biomechanical Study

주관절 외측부의 단계적 손상 모델에서 요측 측부 인대 중첩술이 내반 안정성에 미치는 영향: 생역학적 연구

울 산 대 학 교 대 학 원

의 학 과

소 상 필

The Effect of Radial Collateral Ligament Plication on Varus Stability in a Sequential Injury Model of the Lateral Elbow: A Biomechanical Study

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이 논문을 의학박사 학위 논문으로 제출함

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ABSTRACT

Background: Insufficiency of the radial collateral ligament (RCL) can lead to symptomatic minor instability of the lateral elbow (SMILE). While RCL plication showed favorable clinical outcomes in treating SMILE, its biomechanical impact on varus stability remains unclear, particularly with regards to how effectively RCL plication can restore stability compared to an intact elbow across various degrees of lateral elbow injury.

Purpose: To evaluate the impact of RCL plication on varus stability in a model of sequential lateral elbow injury under controlled varus load.

Methods: A custom-made device was used to test eight fresh-frozen cadaveric specimens (60^{o} of elbow flexion) under a controlled varus load. We examined seven conditions: intact elbow, three sequential injury scenarios (anterior half of the common extensor origin [CEO] release, partial RCL release, and complete RCL release), and three conditions after RCL plication for the respective injury conditions. Each specimen was tested under three varus loads (gravity alone, additional 0.5 and 1 kg applied to the hand). True anteroposterior radiographs of the elbow were acquired in each condition to measure the varus angle and evaluate varus stability.

Results: RCL plication significantly reduced varus angle in cases of anterior half of the CEO and partial RCL release across all tested loads compared to their respective pre-plication states, while a significant reduction was not observed after RCL plication in the condition involving complete RCL release. At all load levels, varus angles in cases of RCL plication for anterior half of the CEO and partial RCL release showed no significant difference from intact elbow. However, RCL plication in complete RCL release exhibited a significantly larger varus angle than the intact elbow.

Conclusion: RCL plication in both anterior half of the CEO and partial RCL releases significantly improved varus stability when compared to their respective injury conditions and achieved varus stability that was comparable to that of the intact elbow. However, RCL plication in complete RCL release did not significantly improve varus stability and exhibited inferior varus stability compared to the intact elbow.

Study Design: Controlled laboratory study.

Keywords: elbow instability; radial collateral ligament; ligament plication; varus stress

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INTRODUCTION

The lateral collateral ligament (LCL) complex of the elbow comprises the radial collateral ligament (RCL), lateral ulnar collateral ligament (LUCL), and annular ligament.[12,18,19] The RCL is a fan-shaped ligament that originates from the inferior surface of the lateral epicondyle and attaches to the annular ligament.[6,22] Function of RCL as a primary stabilizer to lateral elbow instability was proposed by several studies and insufficiency or elongation of the RCL can lead to symptomatic minor instability of the lateral elbow (SMILE) and lateral elbow pain.[1-3,5,10,14,17,28]

In a previous biomechanical study that simulated the varus stress typical of everyday activities at the elbow joint, both pie-crusting and complete release of the RCL demonstrated a significant increase in varus angle compared to the intact elbow. [2] Arthroscopic RCL plication, a technique that was introduced to mitigate minor instability of the lateral elbow, has been shown to yield good levels of patient satisfaction and positive clinical outcomes for the treatment of SMILE.[3] However, while clinical improvements have been observed following RCL plication in treating SMILE, the biomechanical effects on varus stability, particularly the degree to which RCL plication can restore stability that is comparable to an intact elbow after various degrees of lateral elbow injuries, have yet to be fully elucidated.

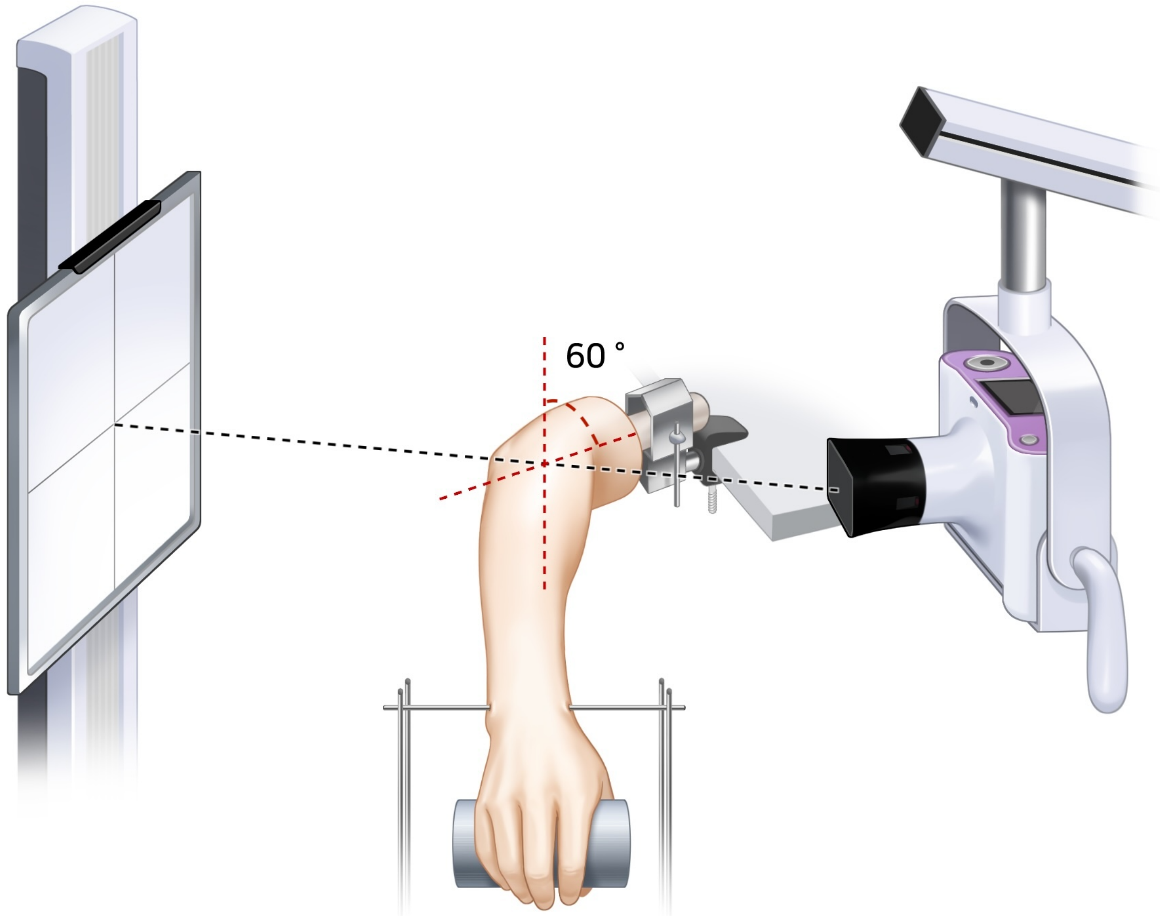
In the present study, we aimed to (1) investigate the biomechanical effects of RCL plication on varus stability in three sequential injury conditions (anterior half of the common extensor origin [CEO] release, partial RCL release, and complete RCL release) and (2) to compare varus stability after RCL plication in each injury condition with that of the intact elbow. We hypothesized that RCL plication in anterior half of the CEO and partial RCL release would significantly improve varus stability when compared to respective injury conditions and would yield comparable varus stability with the intact elbow, while RCL plication in complete RCL release would not significantly improve varus stability when compared to the injured condition and would yield significantly worse varus stability than the intact elbow.

MATERIALS AND METHODS

Specimen preparation

The protocol of this study was approved by Asan Medical Center Institutional Review Board (Approval Number: 2023-0135). Both arms of four male cadaveric specimens were obtained, thus providing eight upper limb specimens from fingertip to the mid-humerus. The mean age of the specimens was 72.3 ± 12.0 years. All specimens were confirmed to be free from gross deformities or instability and showed no radiologic signs of arthritis. The fresh cadaveric specimens were stored at -14°C and thawed overnight at room temperature prior to experimentation. We exposed the bone at the level of the mid-humerus to firmly fix the humerus to a custom-made instrument. The humerus was positioned with the lateral epicondyle directed towards the ceiling and the medial epicondyle towards the floor, thus making the transcondylar axis perpendicular to the floor, to provide true varus stress at the elbow (Figure 1). A 1.6 mm Kirschner wire was then inserted through the distal radius and ulna in a neutral forearm position to control the rotational movements of the forearm and placed on a custom-made holder to maintain a constant varus load along the axis.[4,21] During all test procedures, the elbow was maintained at 60° of flexion to best simulate the varus stress on the lateral elbow experienced during everyday activities.[2,23] A portable X-ray digital camera and detector (MINE 2; Otom, Gwangju, Republic of Korea) were positioned to acquire true anteroposterior plain radiographs of the elbow. All specimen preparations and biomechanical testing were performed by an orthopedic surgeon who had been trained in upper extremity surgery (S.-P.S.).

Figure 1. Setup of the specimen for biomechanical testing and radiographic imaging. The humerus was positioned with the lateral epicondyle facing the ceiling and the medial epicondyle facing the floor. A 1.6 mm Kirschner wire was inserted through the distal radius and ulna in a neutral forearm position and secured in a custom-made holder. The elbow was maintained at 60° of flexion and a portable X-ray digital camera and detector were aligned to capture true anteroposterior plain radiography of the elbow.



Biomechanical Testing

We tested seven conditions for each elbow: intact elbow, three sequential injury conditions (anterior half of the CEO release, partial RCL release, and complete RCL release), and three conditions after RCL plication for the respective injury conditions. Seven testing conditions were prepared in the following order (Figure 2).

1. Basal condition: Intact elbow

2. Anterior half of the CEO release (aCEO-R, Figure 2A). By applying the lateral Kocher approach, skin incision and subcutaneous dissection were performed, and the CEO was exposed. After marking the midline of the CEO, an incision was made along this line, parallel to the muscle fibers. The anterior half of the CEO was then detached from lateral epicondyle to distal direction, taking great care not to injure the underlying LCL complex.

3. RCL plication for anterior half of the CEO release (aCEO-P, Figure 2B). After anterior half of the CEO release, we performed RCL plication using two polydioxanone synthetic 2-0 sutures (PDS II; Ethicon, Somerville, New Jersey, United States). The first suture was passed 5 mm proximal and anterior to the lateral epicondyle, and 5 mm distal and anterior to the radial head. The second suture was passed 5 mm proximal and posterior to the lateral epicondyle, and 5 mm distal and posterior to the radial head. Two stitches were made at 60° of elbow flexion and neutral alignment.

4. Partial RCL release (pRCL-R, Figure 2C). Partial RCL release was achieved through a pie-crusting technique in this study. Following the removal of sutures, a small pin (thinner than the needle of a 2-0 PDS suture) was placed at the previously sutured four points. The boundary of the RCL was marked and pie crusting was performed every 2 mm along the ligament fibers using a 20-gauge needle. As the LUCL was placed under the posterior part of the CEO and pie

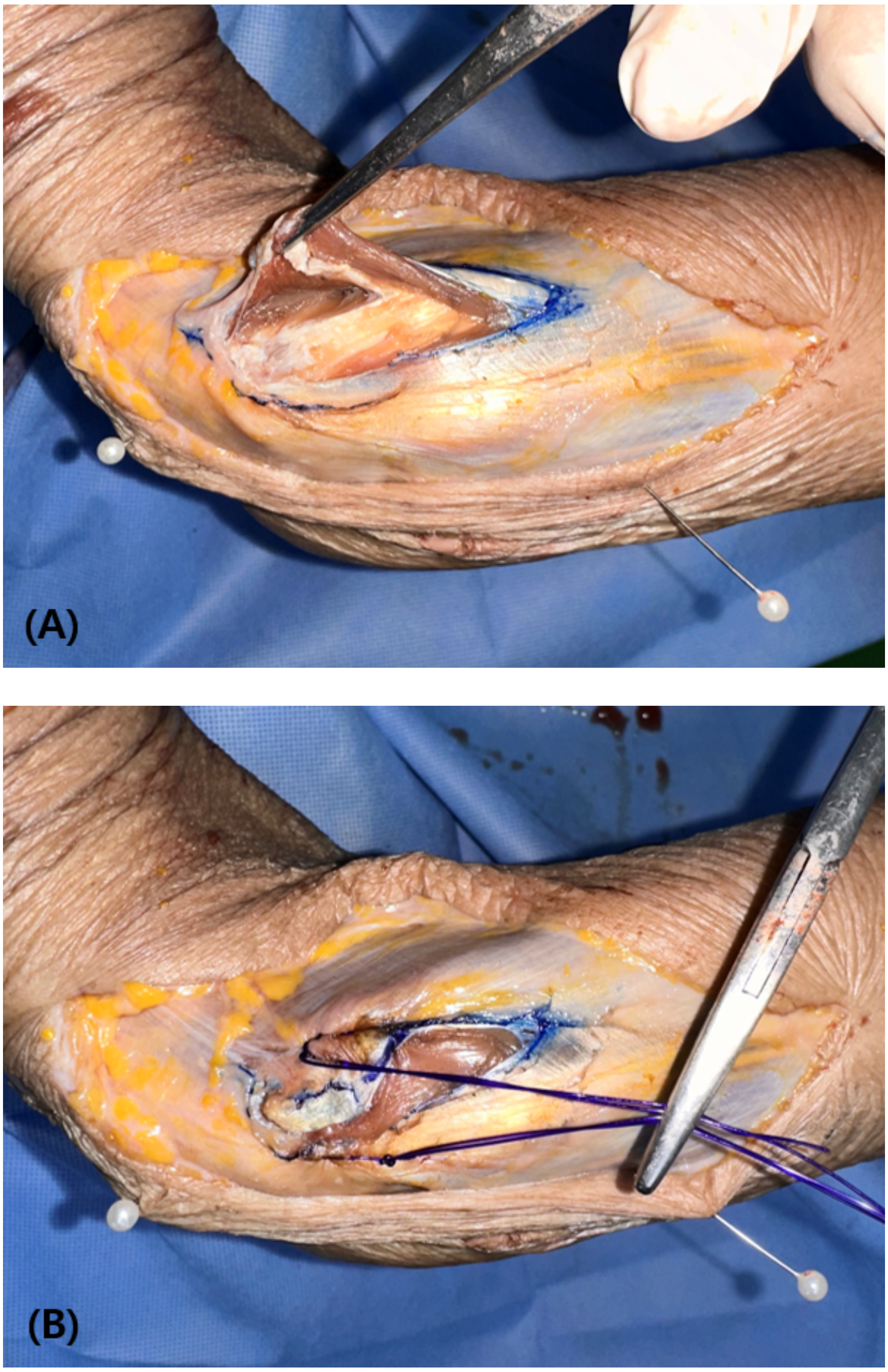
crusting was performed at the RCL which was placed under the anterior half of the CEO, the LUCL was considered as being intact throughout this procedure.

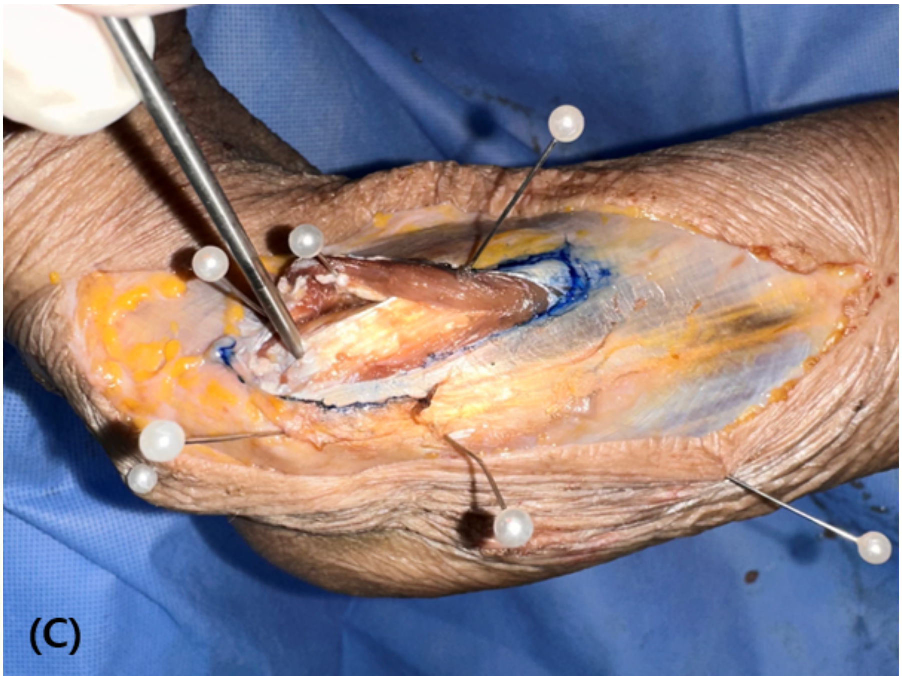
5. RCL plication for partial RCL release (pRCL-P, Figure 2D). After partial RCL release, RCL plication was performed using two polydioxanone synthetic 2-0 sutures. Sutures were passed through the previously marked four points (two anterior and two posterior) and two stitches were made at 60° of elbow flexion and neutral alignment.

6. Complete RCL release (cRCL-R, Figure 2E). Following the removal of sutures, a small pin was placed at the previously sutured four points. Then, the RCL was completely detached from the lateral epicondyle. During this procedure, extreme care was taken not to injure the anterior capsule of the elbow joint and LUCL.

7. RCL plication for complete RCL release (cRCL-P, Figure 2F). After complete RCL release, RCL plication was performed using two polydioxanone synthetic 2-0 sutures. Sutures were passed through the previously marked four points (two anterior and two posterior), and two stitches were made at 60° of elbow flexion and neutral alignment.

Figure 2. Three sequential injury conditions and respective RCL plication conditions for the biomechanical testing. The direction of the shoulder is on the left side of the images while the hand is on the right side. (A) Anterior half of the CEO release; (B) RCL plication for anterior half of the CEO release; (C) Partial RCL release (pie-crusting of RCL); (D) RCL plication for partial RCL release; (E) Complete RCL release; (F) RCL plication for complete RCL release.

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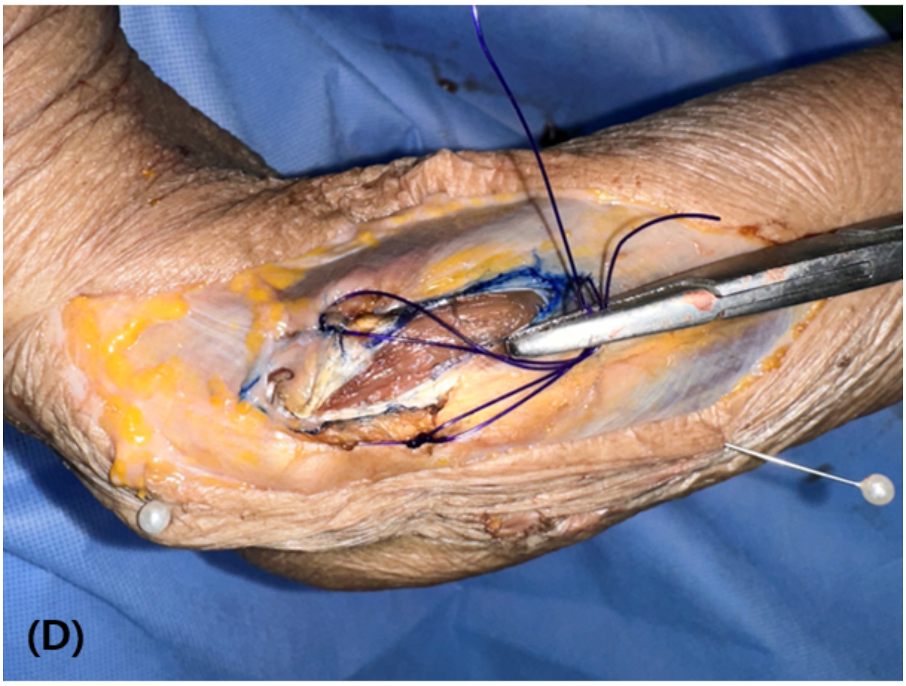
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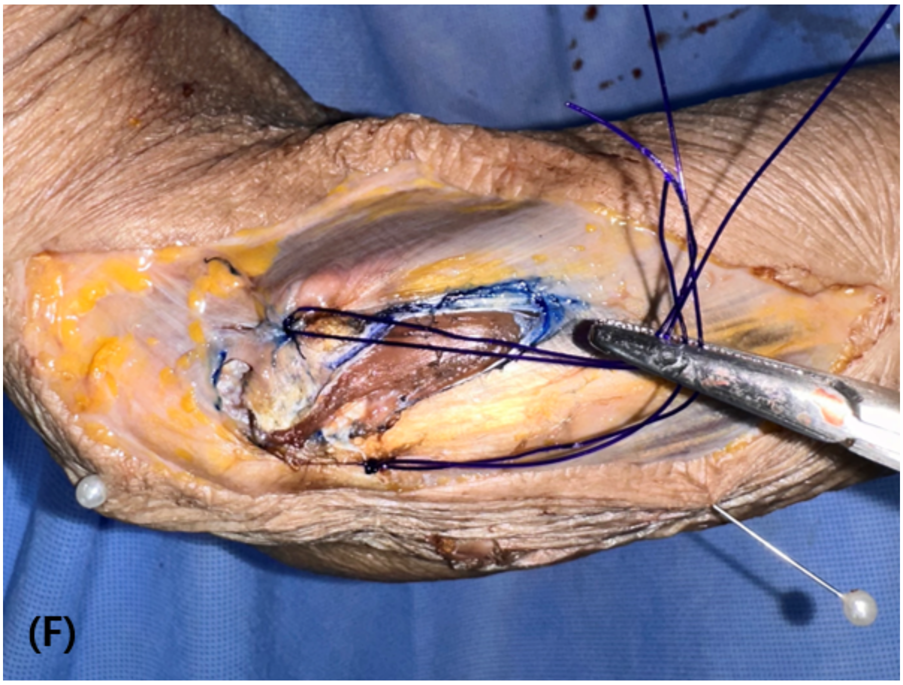
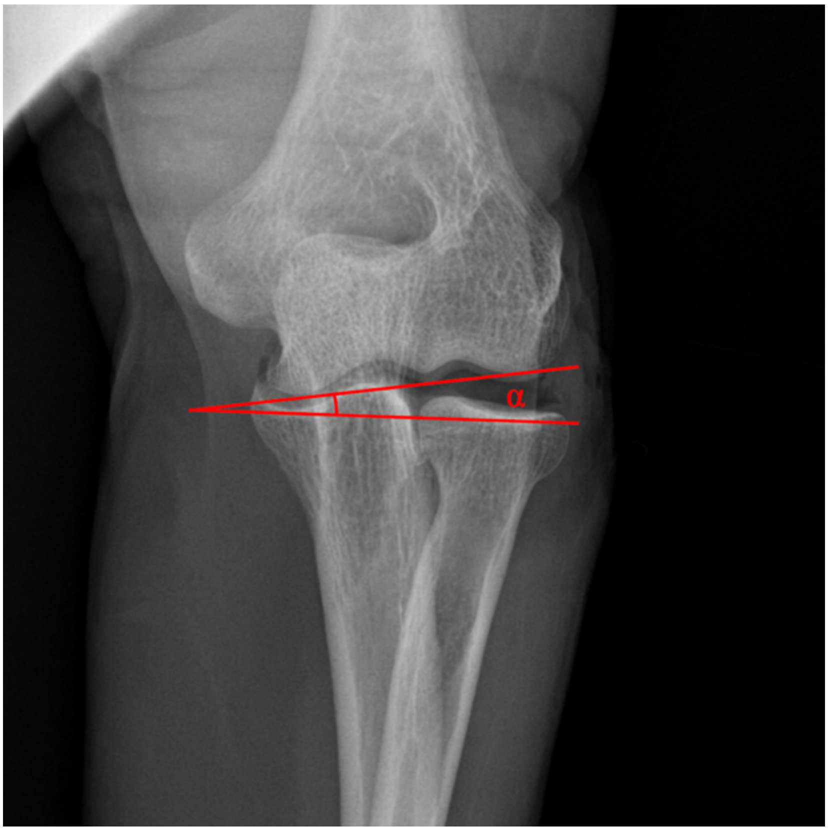


RCL, radial collateral ligament; CEO, common extensor origin

For each condition, we applied three different varus loads: a gravity load with no additional load to the hand, a 0.5 kg load, and a 1 kg load applied to the hand. The exact point of force application was the first web space and the varus torque generated by additional weights to the hand were calculated as torque differences ($\Delta\tau$) to basal gravity load condition based on each specimen's lever arm (from the center of the elbow to the first web space). This allowed us to evaluate the exact effect of the varus load on varus stability in each condition. An anteroposterior plain radiograph was obtained for each testing condition and varus load. Varus stability in each condition was assessed by the varus angle of the elbow (α), defined as the angle between the distal humeral line and the proximal ulno-radial joint line. This method was previously described by Schnetzke et al. and demonstrated excellent interobserver agreement and external validation (Figure 3).[2,24-26]

In this study, we initially compared varus angles between the RCL plication conditions and their respective injury conditions in three varus loads. Then, we compared varus angles between the intact elbow and the RCL plication conditions under three varus loads. In addition, we analyzed the effects of different varus loads on varus angle under different release and plication conditions by performing standardized linear regression analysis.

Figure 3. Measurement of the varus angle (α) of the elbow in an anteroposterior plain radiograph. The angle between the distal humeral line and the proximal ulno-radial joint line was measured.



Statistical Analysis

Continuous variables are reported as means and standard deviations, while ordinal and nominal variables are presented as numbers and percentages. Wilcoxon's signed-rank test was used to compare varus angles between the RCL plication conditions and their respective injury conditions. The Kruskal–Wallis test with post-hoc analysis was used to compare varus angles between the intact elbow and the RCL plication or respective injury conditions. Post-hoc analysis was conducted using the Mann–Whitney U test. To analyze the effects of different varus loads on the varus angle under different release and plication conditions, we conducted standardized linear regression analysis, forcing the interpolant through the origin by creating the equation $\alpha = a \cdot \Delta\tau + b$ ($b = 0$). All statistical analyses were performed using IBM SPSS Statistics for Windows, version 21 (IBM Corp., Armonk, NY, USA) and P-values < 0.05 were considered to be statistically significant.

RESULTS

Effects of a sequential release on varus angle

Across all three varus loads, the sequential release of the lateral elbow resulted in an overall cascading increase in the varus angle (Table 1, Figure 4). In other words, the varus angle for aCEO-R was higher than that of the intact elbow, the varus angle for pRCL-R was higher than that for aCEO-R, and the varus angle for cRCL-R was higher than that for pRCL-R. However, the differences between the intact elbow and aCEO-R were not statistically significant across all three varus loads (Table 2).

Effects of RCL plication on varus angle in a sequential injury model

When assessing the effect of RCL plication, both aCEO-P and pRCL-P exhibited significant decreases in varus angle across all three varus loads, compared to aCEO-R and pRCL-R, respectively, while cRCL-P did not show significant decrease in varus angle when compared to cRCL-R (Table 1 and 3, Figure 4). Both aCEO-P and pRCL-P did not show significant differences in varus angle when compared to the intact elbow, while cRCL-P showed a significantly larger varus angle than the intact elbow (Table 1 and 4, Figure 4).

Table 1. Varus angle (°) of the elbow joint in seven testing conditions under three different varus loads.[a]

	Intact	aCEO-R	aCEO-P	pRCL-R	pRCL-P	cRCL-R	cRCL-P
0kg	2.8 ± 0.5	3.3 ± 0.5	2.6 ± 0.5	4.1 ± 0.7	3.2 ± 0.5	5.2 ± 0.8	4.6 ± 0.8
0.5kg	3.3 ± 0.5	3.7 ± 0.5	3.1 ± 0.4	4.4 ± 0.8	3.7 ± 0.5	5.6 ± 1.0	5.1 ± 0.8
1kg	3.8 ± 0.5	4.2 ± 0.5	3.5 ± 0.4	5.2 ± 0.7	4.1 ± 0.5	6.3 ± 0.9	5.8 ± 1.0

[a]Values are mean ± standard deviation. aCEO-R, anterior half of the CEO release; aCEO-P, RCL plication for anterior half of the CEO release; pRCL-R, partial RCL release; pRCL-P, RCL plication for partial RCL release; cRCL-R, complete RCL release; cRCL-P, RCL plication for complete RCL release.

Table 2. *P*-values for the comparison of the varus angle between the intact elbow and three sequential injury conditions under three different varus loads.[a]

	Intact vs aCEO-R	Intact vs pRCL-R	Intact vs cRCL-R
0kg	0.126	0.004[b]	<0.001[b]
0.5kg	0.114	0.002[b]	<0.001[b]
1kg	0.090	0.003[b]	<0.001[b]

[a]aCEO-R, anterior half of the CEO release; pRCL-R, partial RCL release; cRCL-R, complete RCL release

[b]statistically significant

Table 3. *P*-values for the comparison of the varus angle between the RCL plication conditions and their respective injury conditions under three different varus loads.[a]

	aCEO-R vs aCEO-P	pRCL-R vs pRCL-P	cRCL-R vs cRCL-P
0kg	0.031[b]	0.012[b]	0.172
0.5kg	0.039[b]	0.015[b]	0.206
1kg	0.013[b]	0.010[b]	0.269

[a]RCL, radial collateral ligament; aCEO-R, anterior half of the CEO release; aCEO-P, RCL plication for anterior half of the CEO release; pRCL-R, partial RCL release; pRCL-P, RCL plication for partial RCL release; cRCL-R, complete RCL release; cRCL-P, RCL plication for complete RCL release.

[b]statistically significant

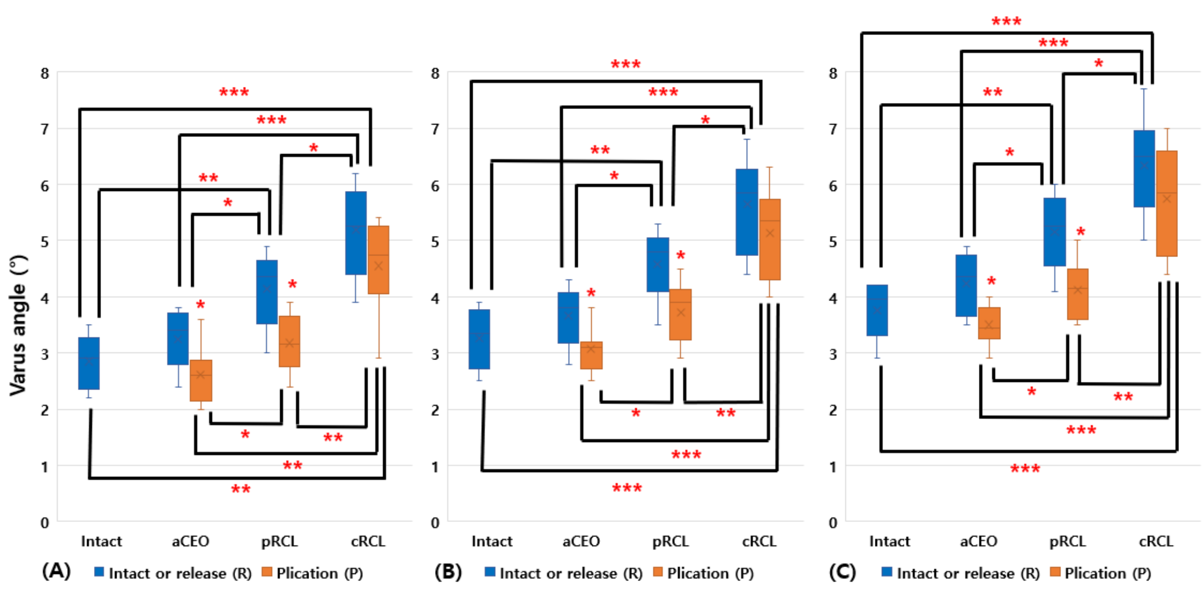
Table 4. *P*-values for the comparison of the varus angle between the intact elbow and three RCL plication conditions under three different varus loads.[a]

	Intact vs aCEO-P	Intact vs pRCL-P	Intact vs cRCL-P
0kg	0.317	0.226	0.003[b]
0.5kg	0.342	0.090	<0.001[b]
1kg	0.266	0.203	<0.001[b]

[a]RCL, radial collateral ligament; aCEO-P, RCL plication for anterior half of the CEO release; pRCL-P, RCL plication for partial RCL release; cRCL-P, RCL plication for complete RCL release.

[b]statistically significant

Figure 4. Varus angle of the elbow joint in the intact elbow, three sequential injury conditions, and three conditions after RCL plication for the respective injury conditions under three different varus loads: (A) gravity varus load, (B) with an additional 0.5 kg varus load to the hand, (C) with an additional 1 kg varus load to the hand.



RCL, radial collateral ligament; aCEO, anterior half of the common extensor origin; pRCL, partial radial collateral ligament; cRCL, complete radial collateral ligament

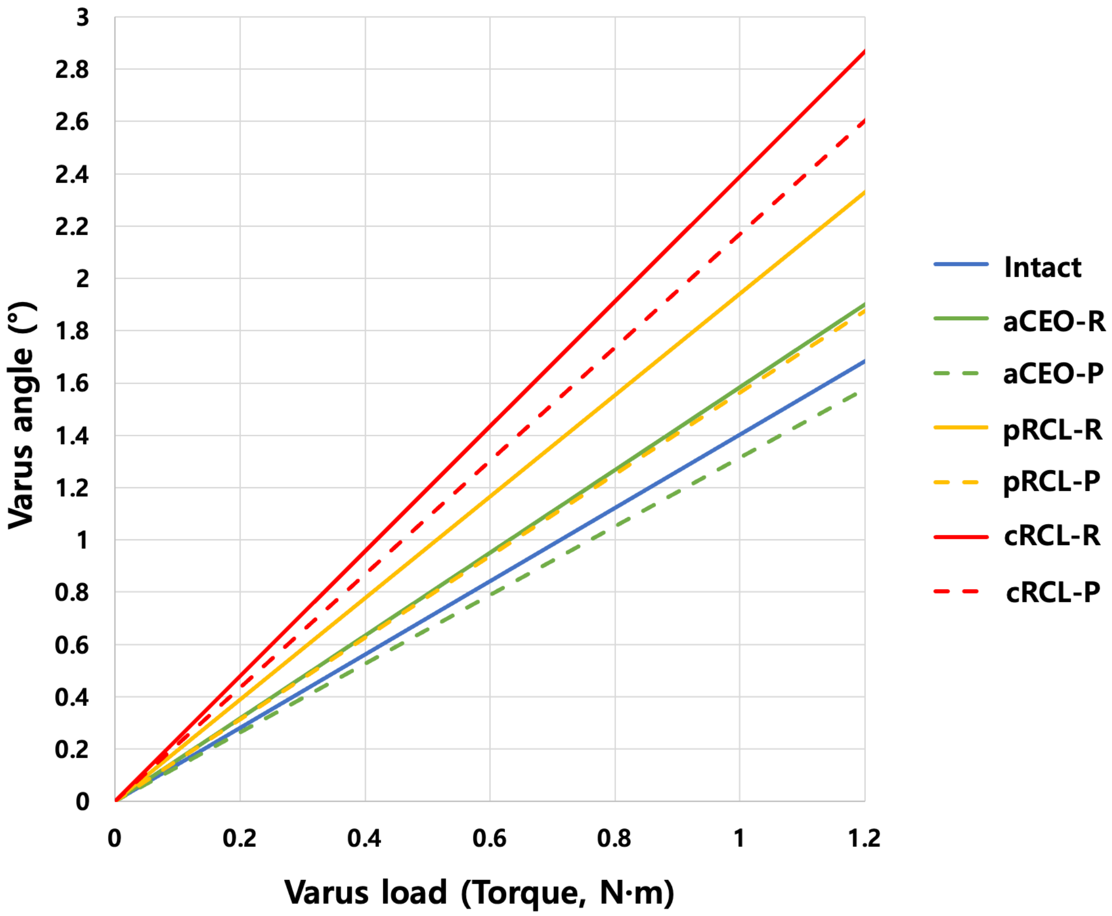
Boxes show the interquartile range, and the end of the bar represents the maximum and minimum data value.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$; * between intact, aCEO, pRCL, and cRCL (both release and plication) represent significant changes between each release (or plication) step, while * at the top of plication in each condition indicates significant changes after RCL plication when compared to the respective injury condition.

Effects of varus loads on varus angle in the seven testing conditions

Effects of varus loads on varus angle across the seven testing conditions with sequential release and respective RCL plication were mapped according to the equation $\alpha = a \cdot \Delta\tau + b$ ($b = 0$), derived from a standardized linear regression analysis that forced the interpolant through the origin (Figure 5). A higher slope (a) indicates lower varus stability and vice versa. In all the seven testing conditions, increase of varus load led to subsequential increase in varus angle and the slope of aCEO-P ($a = 1.3135$) was the lowest of the seven conditions, followed by intact elbow ($a = 1.4032$), pRCL-P ($a = 1.5619$), aCEO-R ($a = 1.5829$), pRCL-R ($a = 1.9395$), cRCL-P ($a = 2.1684$), and cRCL-R ($a = 2.3889$).

Figure 5. Effects of varus loads on varus angle in the seven testing conditions with sequential release and respective RCL plication.



RCL, radial collateral ligament; aCEO-R, anterior half of the CEO release; aCEO-P, RCL plication for anterior half of the CEO release; pRCL-R, partial RCL release; pRCL-P, RCL plication for partial RCL release; cRCL-R, complete RCL release; cRCL-P, RCL plication for complete RCL release

DISCUSSION

In this study, we assessed varus stability by measuring the varus angle after the sequential release of the lateral elbow and respective RCL plications. RCL plication in anterior half of the CEO and partial RCL release led to a significant reduction in varus angle when compared to the respective injury conditions across all varus loads. However, RCL plication in the complete RCL release did not lead to a significant reduction of the varus angle. The varus angle after RCL plication in the anterior half of the CEO and partial RCL release did not show a significant difference when compared to the intact elbow, while RCL plication in the complete RCL release resulted in a significantly larger varus angle than the intact elbow.

Several studies have reported clinical outcomes following arthroscopic LCL complex or RCL plication in cases of rotatory or varus instability.[1,3,8,16,27] Arthroscopic LCL imbrication was first introduced by Smith et al., who reported satisfactory results in over 20 patients.[27] Arrigoni et al. focused on the RCL within the LCL complex and introduced arthroscopic RCL plication to reduce the lateral laxity in SMILE that results from the patholaxity of the lateral ligaments due to repetitive varus-pronation stress on the elbow.[1,3] Single Assessment Numeric Evaluation score was improved and good or excellent subjective results were reported in 96.3% of patients with recalcitrant lateral epicondylitis following arthroscopic RCL plication due to signs of SMILE. However, 41% of patients did not achieve a full range of motion at the final follow-up, a potential side effect of RCL plication. The results of the present study, which demonstrated improvements in varus stability after RCL plication for the anterior half of the CEO and partial RCL release, support these previous positive clinical outcomes.

The primary aim of this study was to determine to what degree RCL plication could restore varus stability to levels comparable to the intact elbow. Both this and a previous biomechanical study demonstrated a sequential worsening of varus stability with sequential releases of lateral elbow tissues, from anterior half of the CEO to partial and complete RCL release.[2] After RCL plication, varus angle in both anterior half of the CEO and partial RCL releases were comparable to that of the intact elbow, whereas the varus angle in complete RCL release remained significantly larger than that of the intact elbow. These findings suggest anterior half of the CEO and partial RCL release as the possible candidates for RCL plication.

With regards to anterior half of the CEO release, RCL plication led to a significant reduction in the varus angle when compared to the injury condition and showed comparable varus angles with the intact elbow across all varus loads; however, release alone did not lead to a significant increase of the varus angle when compared to the intact elbow. This finding can be interpreted in two ways. First, anterior half of the CEO release might not lead to sufficient varus instability to necessitate RCL plication. A previous study, which tested changes in varus angle in the intact elbow and three sequential injury models—similar to our study—revealed a significant increase in varus angle after anterior half of the CEO release compared to the intact elbow, only under gravity varus and defined pie-crusting of the RCL as the minimal procedure to significantly increase varus angle.[2] Despite a significant improvement in varus stability after RCL plication, anterior half of the CEO release itself might not generate sufficient varus instability to undergo RCL plication; furthermore, under these circumstances, plication could result in overcorrection and undesired side effects such as limited motion, as previously reported in 41% of patients undergoing arthroscopic RCL plication who did not achieve a full range of motion at the final follow-up.[3] Second, considering the tendencies for changes in the varus angle between the intact elbow and after the anterior half of the CEO release that were observed in both studies, it is possible that future studies, incorporating a larger number of specimens, might show statistical significance. In addition, forearm muscles, including the extensor carpi radialis longus, brevis, and extensor carpi ulnaris, showed clear resistance against varus moments when tested by electromyography and could function as a dynamic stabilizer for the lateral elbow instability. Therefore, this condition should not be overlooked, and a multifaceted approach is required to determine the necessity of RCL plication under these circumstances.[7,11,15]

RCL plication in the partial RCL release led to a significant reduction in the varus angle under all varus loads when compared to the released state and matched the varus angle of the intact elbow. Partial RCL release condition, which leads to a significant increase in the varus angle in a minimally invasive manner, clinically reflects SMILE and this is considered as the most appropriate condition for RCL plication among three injury conditions in this study. To be more precise, the slope (a) of the equation $\alpha = a \cdot \Delta\tau + b$ ($b = 0$), calculated in this study to investigate the effects of varus loads on the varus angle under different release and plication conditions, demonstrated that the slope of the intact elbow was lower than that of RCL plication in the partial RCL release and higher than that of RCL plication in the anterior half of the CEO release. Considering that a higher slope generated by this equation indicates lower varus stability, these findings indicate that RCL plication in the condition between anterior half of the CEO release and partial RCL release would restore the varus stability to a status most comparable to that of the intact elbow. In cases involving complete RCL release, which typically correlates with a complete tear of the RCL and not just minor instability, simple plication did not significantly improve varus stability and yielded significantly inferior varus stability than the intact elbow. Further tensioning procedures, such as ligament repair or reconstruction, might be required in cases involving complete RCL release.[14]

Limitations

There were several limitations to this study that need to be considered. First, in this study, RCL plication was performed using an open technique, differed from the arthroscopic plication technique that was introduced previously.[1,3] In addition, the open technique utilized in the present study could only generate an outside-in injury model, meaning that a model of RCL release could not be achieved without releasing the anterior half of the CEO. To evaluate the true effect of pure RCL release and plication, future studies need to generate an inside-out injury model and perform plication with the arthroscopic technique, thus allowing comparisons with the finding presented here. Second, the application of several release and plication conditions to a single specimen could have weakened soft tissue tensions during experimental progression. To mitigate this, small pins, thinner than the needle of 2-0 PDS sutures, were used at previous suture points during further plications to avoid weakening of soft tissues by passing sutures through different points. Third, this study was conducted with the elbow flexed at 60°; this may not represent the most optimal condition for recovering varus stability by RCL plication or for assessing the impact of lateral elbow soft tissues on varus stability. However, we established this condition to best simulate varus stress on the lateral elbow during everyday activities and to maintain a consistent experimental setting throughout our investigations.[2,23] Fourth, inborn limitation of the cadaveric study was that healing process after RCL plication was not accounted, differing from a real clinical scenario and dynamic function of muscles, known to be varus stabilizers, were not reflected due to its static experiment setting.[7,9,13,20] Finally, although statistically significant differences or changes in the varus angle were achieved throughout this study, these changes may differ from clinically significant differences or changes. Despite these limitations, our study demonstrated the biomechanical effects of RCL plication on varus stability at different stages of lateral elbow injury and proposed the adequate condition of lateral elbow injury that could lead to the biomechanical recovery of varus stability to levels comparable to the intact elbow after RCL plication.

CONCLUSION

RCL plication in both anterior half of the CEO and partial RCL releases significantly improved varus stability when compared to their respective injury conditions and achieved varus stability that was comparable to that of the intact elbow. However, RCL plication in complete RCL release did not significantly improve varus stability and exhibited inferior varus stability compared to the intact elbow.

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요 약 (국 문)

배경: 요측 측부 인대의 결핍은 외측 주관절의 증상을 동반한 경미한 불안정성을 유발할 수 있다. 요측 측부 인대 중첩술은 외측 주관절의 증상을 동반한 경미한 불안정성을 치료하는데 있어 호의적인 임상 결과를 보여주었지만, 내반 안정성에 미치는 생역학적 역할은 불확실하며, 특히 요측 측부 인대 중첩술이 다양한 정도의 외측 주관절 손상에서 어느 정도까지 정상 주관절과 비교하였을 때 내반 안정성을 효과적으로 회복시킬 수 있을지에 대해서는 알려져 있지 않다.

목적: 통제된 내반 부하의 연속적 외측 주관절 손상 모델에서 요측 측부 인대 중첩술이 내반 안정성에 미치는 영향을 평가해보고자 한다.

대상 및 방법: 여덟 개의 신선 냉동 카데바 표본 (60 도 주관절 굴곡)을 통제된 내반 부하에서 평가하기 위하여 맞춤형 기기가 사용되었다. 정상 주관절, 3 개의 연속 손상 상태 (총신전근의 전방 절반의 유리, 부분 요측 측부 인대 유리와 완전 요측 측부 인대 유리)와 3 개의 손상 상태에 대한 각각의 요측 측부 인대 중첩술 상태를 포함한 7 개의 상태에 대해 실험하였다. 각 표본은 3 개의 내반 부하 상태 (중력 부하만 작용된 경우, 0.5 kg 과 1kg 의 추가 부하가 손에 적용된 경우)에서 실험되었다. 각각의 상태에서 촬영된 전후방 주관절 방사선 사진을 이용하여 내반 각도를 측정하고, 내반 안정성을 평가하였다.

결과: 총신전근의 전방 절반의 유리와 부분 요측 측부 인대 유리 상태에서 요측 측부 인대 중첩술을 시행한 후 각각의 중첩술을 시행하기 전 상태와 비교하였을 때 모든 부하 상태에서 내반 각도가 유의미하게 감소되었으나, 완전 요측 측부 인대 유리 상태에서 요측 측부 인대 중첩술을 시행하였을 때에는 내반 각도의 유의미한 감소가 관찰되지 않았다. 총신전근의 전방 절반의 유리와 부분 요측 측부 인대 유리 상태에서 요측 측부 인대 중첩술을 시행한 후, 정상 주관절과 비교하였을 때 모든 부하 상태에서 내반 각도의 유의미한 차이가 없었다.

하지만, 완전 요측 측부 인대 유리 상태에서 요측 측부 인대 중첩술을 시행한 후에는 정상 주관절과 비교하여 유의미하게 큰 내반 각도가 관찰되었다.

결론: 총신전근의 전방 절반 유리와 부분 요측 측부 인대 유리 상태에서 요측 측부 인대 중첩술을 시행한 후, 각각의 손상 상태와 비교하여 내반 안정성이 유의미하게 호전되었고, 정상 주관절과 비교하여 견줄만한 내반 안정성을 확보할 수 있었다. 하지만, 완전 요측 측부 인대 유리 상태에서는 요측 측부 인대 중첩술을 시행한 후, 내반 안정성의 유의미한 호전이 없었고, 정상 주관절과 비교하여 열등한 내반 안정성이 확인되었다.

연구 설계: 통제실험연구

중심 단어: 주관절 불안정성; 요측 측부 인대; 인대 중첩술; 내반 부하