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Biomechanical Comparison of Plate Configuration in Comminuted Olecranon Fracture with Small Triceps Fragment

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Abstract

Biomechanical Comparison of Plate Configuration in Comminuted Olecranon Fracture with Small Triceps Fragment

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Background

Although preventing triceps fragment displacement is essential for treating an olecranon fracture, we frequently encounter situations in which only a few screws can be fixed to the triceps fragment. The aim of this study was to compare the stability of double-plate fixation and posterior plate fixation for olecranon fractures when the triceps fragment was small and only two screws could be inserted.

Methods

A composite ulna model was used to simulate olecranon fracture.

Four groups were formed consisting of double-plate and posterior plates with cortical and locking screws. The cyclic loading test was conducted for 500 cyclic loads of 5-50N on a specimen to measure micromotion and displacement of the gap caused by light exercise. The load-to-failure test was performed by applying a load until fixation loss, defined as when the fracture gap increased by 2 mm or more or catastrophic failure occurred, to measure the maximum load. Eight samples per group were tested through the pilot study.

Results

All groups were stable with a micromotion of less than 0.5 mm. However, the mean micromotion showed significant differences between the four groups ($p < 0.001$, Table 1). In the mean micromotion during exercise, posterior plating with cortical screws was the most stable (0.09 ± 0.02 mm) while double-plating with cortical screws was the most unstable (0.42 ± 0.11 mm). At the maximum load, posterior plating with locking screws was the strongest (205.3 ± 2.8 N) while double-plating with cortical screws was the weakest (143.3 ± 27.1 N). There was no significant difference in displacement after light exercise between the groups.

Conclusions

This study showed that when two triceps screws were used, both groups were stable during light exercise, but posterior-plating was stronger than double-plating.

keywords : Olecranon Process/surgery, Bone plates, Biomechanical Phenomena, Fractures, Comminuted/surgery

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Introduction

Olecranon fractures are common, accounting for 10% of all upper extremity fractures.(1) Fracture patterns vary from nondisplaced simple to comminuted fractures with dislocation.(2) The triceps fragment receives significant tension force in any olecranon fracture (Fig. 1).(3,4) When tension force is applied to the triceps fragment, rotational displacement occurs because the trochlea acts as an obstacle. For the extensor mechanism, preventing this displacement is essential for treating an olecranon fracture.(5,6)

Plate fixation has been recommended for treating comminuted olecranon fractures.(7) A posterior plate is traditionally used for olecranon fractures with clinically favorable results.(8) However, problems such as irritation and infection related to implant prominences have been raised.(9,10) Hardware-related symptoms from posterior plates reached 67%.(10) To solve the posterior plate problems, lateral plate fixation was proposed,(11) and low-profile double-plate fixation to both lateral sides was developed.(12)

Positionally, the posterior plate can block rotational displacement of the triceps fragment better than the double-plate. Despite the locational advantage, previous biomechanical studies have reported that double-plating had biomechanical stability similar to posterior plating for olecranon fractures.(12-15) However, the settings of the biomechanical tests are not completely identical to the real situation.

Previous studies were performed in a setting where enough screws, three or more, could be inserted into the triceps fragment. Still, we frequently encounter situations in which only a few screws can be fixed to the triceps fragment. More severe comminution makes the size of the triceps fragment smaller. For comminuted olecranon fractures, it is recommended to add another fixation method such as interfragmentary screws to the plating.(5,16,17) It is possible to fix the triceps fragment with only a few screws when there is interference by the additional fixation construct. As the number of the triceps fragment screws decreases, the plate position's influence on stability can vary.

To the best of our knowledge, no studies have investigated the stability of plates with fewer than three triceps screws. Therefore, the objective of this study was to compare the stability of a double-plate and a posterior plate for olecranon fractures with a small triceps fragment fixed with only two screws.

Materials and methods

1. Specimen preparation

This study was approved by the institution's Institutional Review Board (No. 07-2020-294 of Seoul National University Boramae Hospital). This was a biomechanical study using a fourth-generation composite ulna model (Sawbones, Pacific Research Laboratories, Vashon, Washington, USA). Plates using this study have been

commercially used in clinical practice for olecranon fractures, including 1.8-mm double plates and 4.0-mm posterior plates (Arix elbow system, Jeil Medical, Seoul, South Korea). To determine the effect of the screw on stability, the composition of the triceps screws was divided into cortical and locking groups. The locking screw has angular stability, which reduces plate's influence. In contrast, the cortical screw compresses the fragment onto the plate, so the plate position has a significant effect on the stability.[18] Four groups were formed consisting of double-plate and posterior plates with cortical and locking screws: ① the double plate-cortical screw (DC) group, ② the double plate-locking screw (DL) group, ③ the posterior plate-cortical screw (PC) group, and ④ the posterior plate-locking screw (PL) group.

A comminuted fracture was made by removing a 5-mm bone block from an area 1-cm distal to the olecranon tip.(11) The plate position for each specimen was made the same using a customized frame. A fixed angle drill guide was used as much as possible when drilling the cortical/locking screw hole. The diameter of the cortial and locking screws, called triceps screws, inserted into the triceps fragment was the same at 2.8 mm. At the ulnar shaft, the posterior plate was fixed with five 3.5-mm screws and the double plate was fixed with eight 2.8-mm screws. The shaft fixation of each plate was sufficient. It did not affect the biomechanical test results. An additional 3.5-mm screw, called a load screw, was inserted independently of the plate. The load screw applies a force to the triceps fragment. The prepared specimens are presented in Figure 2.

2. Testing setup

The test setup was modified based on methods in previous studies.(14,15,19-22) The mechanical testing machine was an Instron E3000 (Instron Engineering Corporation, Norwood, Massachusetts, USA). All specimens were fixed on a hollow cylindrical fixture customized for this study (Fig. 3). The elbow joint angle was fixed at 90 degrees. The load was applied to the load screw in the direction of 90 degrees of the ulna axis. For each specimen, the distance from the rotational axis to the load cell was made the same. The same distance equalized the length of the lever arm and the ratio of the load cell's moving distance to fracture displacement. To simplify the measurement, the load cell's moving distance was assumed to be an approximation of the micromotion during the tests. Fixation loss was defined as an increase of 2 mm or more in the moving distance of the load cell or when a catastrophic failure occurred.

3. Cyclic loading test

The cyclic loading test aimed to measure the stability during light exercise of the elbow. A light exercise force was assumed to be 5 N to 50 N.(14,23) Thus, a force of 5 N-50 N was applied to a specimen 500 times at a frequency of 1 Hz. During the experiment, the average moving distance of the load cell was regarded as the micromotion during exercise. The difference in gap distance at the anterior and posterior cortex before and after the test was assumed to be the displacement after exercise. The gap distance was measured using a digital caliper (Mitutoyo, Neuss, Germany).

4. Load-to-failure test

A load-to-failure test was performed on the same specimen after the cyclic loading test to measure the maximum load until fixation

loss. The load was increased 1 mm/min from 0 N.

5. Statistical analysis

Sample size analysis was performed using G*power (Version 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany).[24] A pilot study of the load-to-failure test with three samples in each group revealed that the average maximum load was DC 146 N, DL 173 N, PC 186 N, and PL 205 N. The standard deviation of the PL group used as the reference was 2N. With an α setting of 0.05 and 80% power, the appropriate sample size was eight per group.

For statistical analysis of result, R (Version 3.6.3, R Foundation for Statistical Computing, Vienna, Austria) and Rex (Version 3.5.0, RexSoft Inc., Seoul, South Korea) software were used. The Kruskal-Wallis test was used to compare variables between the four groups and Dunn-Bonferroni's method was used for the post-hoc test. The Wilcoxon signed-rank test was used to compare gaps before and after a cyclic loading test. A p-value of less than 0.05 was regarded as statistically significant.

Results

1. Cyclic loading Test

All groups were stable with a micromotion of less than 0.5 mm. However, the mean micromotion showed significant differences between the four groups ($p < 0.001$, Table 1). The difference in stability increased when the triceps fragment was compressed onto a plate using a cortex screw. The PC group was the most stable, whereas the DC group was the most unstable. The mean micromotion was significantly different for the DC group vs. the PC

group ($p < 0.001$), the DC group vs. the PL group ($p = 0.002$), and the DL group vs. the PC group ($p = 0.04$) (Fig. 4). When comparing the gap difference before and after the test, only the posterior cortex of the DC group showed a statistically significant difference ($p = 0.023$). The displacement after the cyclic loading test was not significantly different between the four groups (anterior cortex, $p = 0.931$; posterior cortex, $p = 0.316$).

2. Load-to-failure test

The maximum load was significantly different between the four groups ($p < 0.001$). The maximum load was the strongest for the PL group and weakest for the DC group (Table 2). There was a significant difference in the maximum load in the DC group vs. the PC group ($p = 0.03$), the DC group vs. the PL group ($p < 0.001$), and the DL group vs. the PL group ($p = 0.002$) (Fig. 5).

Discussion

Handling triceps fragments in olecranon fractures is essential to maintaining the extensor mechanism. The number of triceps screws is important when affixing the triceps fragment. Intramedullary screws, so-called home run screws, can also enhance stability. Three or more triceps screws and intramedullary screws provide sufficient stability to hold triceps fragments, reducing the effect of the plate position. Gordon et al.(12) reported that posterior plating with intramedullary screws had the highest maximum load and that simple posterior plating and double-plating had similar stability. They used three cancellous screws for posterior plating and four cancellous screws for double-plating on the triceps. Wegmann et al.(13) reported that there was no difference in reduction quality between posterior

plating with five cortical triceps screws, posterior plating with four locking triceps screws, and double plating with six locking triceps screws in Monteggia-like proximal ulnar fractures. Hackle et al.(14) reported that double-plating had superior or similar stability to posterior plating in micromotion between 25N and 80N using four cortical triceps screws including intramedullary screws. Hoelscher-Doht et al.(15) concluded that when using four locking triceps screws, the low-profile double-plate had a comparable maximum load to the posterior plate. Wagner et al.(25) reported that posterior plating with three locking triceps screws and double-plating with four locking triceps screws had similar stability when intramedullary screws were used in a study using an osteoporotic olecranon cadaver.

In comminuted olecranon fractures, plating-only is frequently impossible for appropriate fixation and bony union. To fix fragments or bone grafts, a variety of fixation methods can be used in addition to plating (e.g., interfragmentary screws or cerclage wiring).(16,17,5,2) If composite fixation is performed or the triceps fragment is too small, sufficient screw insertion into the triceps fragment cannot be achieved. In the past, when the triceps fragment was small, fragment excision and triceps advancement were recommended for low-demand patients and triceps fragments with less than 50% articulation.(26) However, Bell et al.(27) demonstrated that small triceps pieces contributed to coronal stability. Since then, methods of handling small triceps fragments and extensors have been studied. Izzi et al.(5) recommended off-loading triceps sutures to augment plating when the triceps fragment is small. Wild et al.(17) reported a median improvement of 48% in the maximum strength when suture augmentation was performed in addition to plate fixation. Our study

showed that both groups were stable during light exercise, but that posterior plating was more stable than double-plating when the number of triceps screws was two. This is because a plate posteriorly located blocks the rotational displacement of the triceps fragment better than a double-plate when the triceps screws are insufficient (Fig. 6).

The double-plate was proposed to solve the irritations of the posterior plate, but the double-plate does not completely replace the posterior plate. In two retrospective studies led by Ellwein,(28,29) a total of 126 patients were analyzed and reported no statistical difference in clinical outcomes, including implant-related irritation, between double and posterior plates. Morwood et al.(16) recommended additional fixation, such as a lateral plate and cerclage wiring after posterior plating for an olecranon fracture with sagittal split fragments. Our results suggest a posterior plate rather than a double-plate for small triceps fragments. In summary, studies including our study suggest that double-plating can be used as an alternative to posterior plating in less comminuted olecranon fractures, but it is not recommended when comminution is severe.

This study had several limitations. First, the statistical power was weak because the number of specimens was small. The results would be more precise if a larger number of specimens were used because parametric analysis would be possible. Second, the results could be influenced by plate design. The double plate was a 1.8-mm-thick low-profile plate and the posterior plate was 4.0-mm thick. Different results may occur for other plate designs depending upon the manufacturer. The third limitation was the method of applying pressure using a load screw. We applied force directly to the triceps fragment using a load screw to remove interference caused by the

polyester band or steel wire used in previous studies. However, catastrophic failure occurred in two of eight specimens in the PL group in the load-to-failure test. In the catastrophic failure specimens, the triceps fragment could not withstand the load applied to the load screw within the triceps fragment (Fig. 7). The load at the time of the catastrophic failure of two specimens was 202.9N and 209.1N as shown in the Supplemental Digital Content (Supplemental data). These results were higher than the average of the other groups, so there was little influence on the statistical analysis. Our study setup using load screws is not suitable for biomechanical experiments with large loads above 200N.

Conclusion

This study showed that when two triceps screws were used, both groups were stable during light exercise, but posterior-plating was stronger than double-plating.

Author Contributions

Conceptualization: YL, YHL
Data curation: YL
Formal analysis: YL
Funding acquisition: YHL
Methodology: YL, BWC, MBK, YHL
Software: YL
Supervision: BWC, MBK, YHL
Visualization: YL
Writing - original draft: YL, review & editing: YL, BWC, MBK, YHL

Tables

Table 1 Mean gapping and displacement in the cyclic loading test

Group	Gapping during the test	Displacement after the test	
		Anterior cortex	Posterior cortex
Double-cortical	0.42 ± 0.11 (0.25 – 0.58)*	0.02 ± 0.18 (-0.78 – 0.31)	0.14 ± 0.14 (-0.13 – 0.16)†
Double-locking	0.17 ± 0.03 (0.12 – 0.21)*	0.05 ± 0.10 (-0.16 – 0.16)	0.08 ± 0.14 (-0.17 – 0.11)
Posterior-cortical	0.09 ± 0.02 (0.05 – 0.12)*	0.03 ± 0.13 (-0.37 – 0.22)	0.03 ± 0.19 (-0.14 – 0.28)
Posterior-locking	0.12 ± 0.04 (0.07 – 0.17)*	0.04 ± 0.10 (-0.12 – 0.22)	-0.03 ± 0.22 (-0.44 – 0.20)

The values are presented as the mean ± standard deviation, with ranges in parentheses. All values are in mm.

* Significant difference between groups ($p < 0.05$)

† Significant difference in the gap before and after the test ($p = 0.023$)

Table 2 Mean maximum load in load-to-failure test

Group	Maximum load (range)
Double-Cortical	143.3 ± 27.1 (109.6 - 188.2) [a, b]
Double-Locking	175.1 ± 3.3 (170.2 - 180.4) [c]
Posterior-Cortical	185.5 ± 5.0 (177.1 - 190.5) [b]
Posterior-Locking [d]	205.3 ± 2.8 (200.9 - 209.1) [a, c]

The values are presented as the mean ± standard deviation, with ranges in parentheses. All values are in N.

[a, b, c] Significant difference between groups (p-value < 0.05)

[d] Two out of eight had a catastrophic failure.

Figures

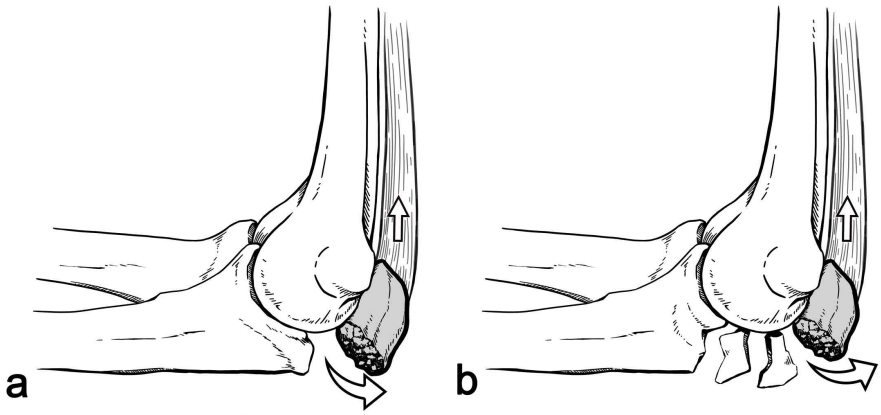

Figure 1. The triceps fragment that receives tension force becomes a rotational displacement by the trochlea.

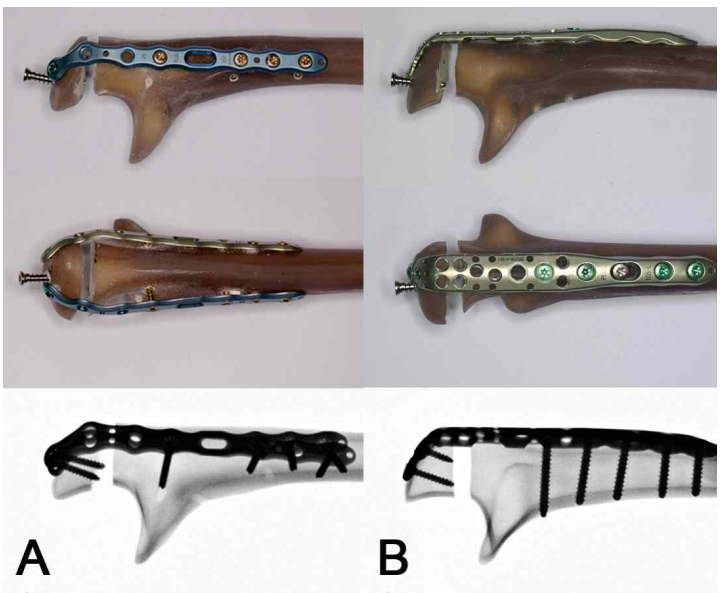

Figure 2. Specimens simulated for a comminuted olecranon fracture with retained implants. (A) Double plate. (B) Posterior plate.

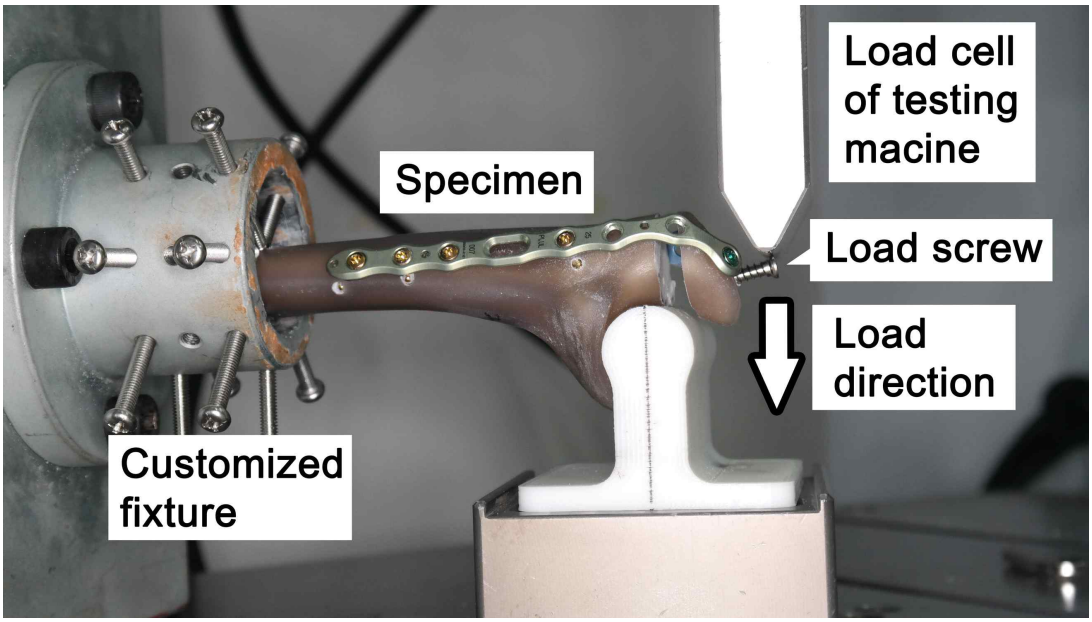

Figure 3. A vertical load applied to the triceps fragment to simulate a triceps pull.

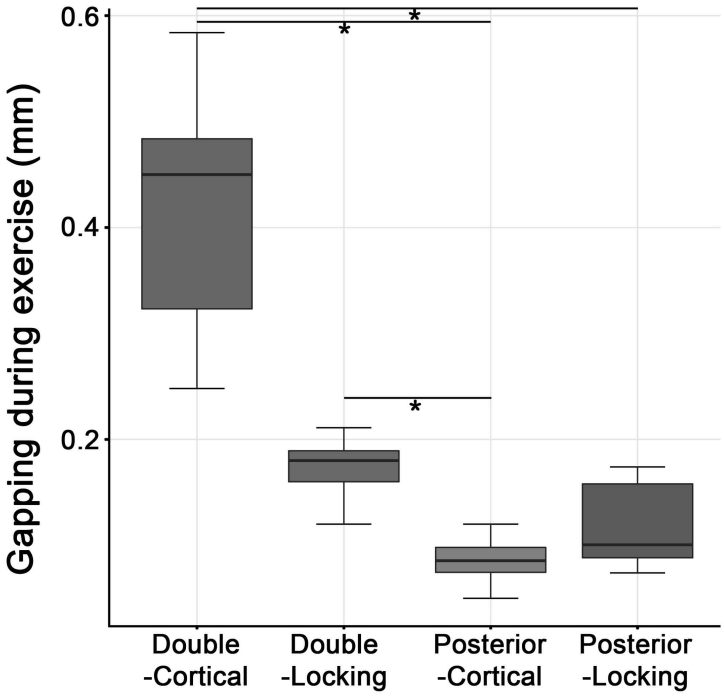

Figure 4. Gapping during exercise in the four groups.

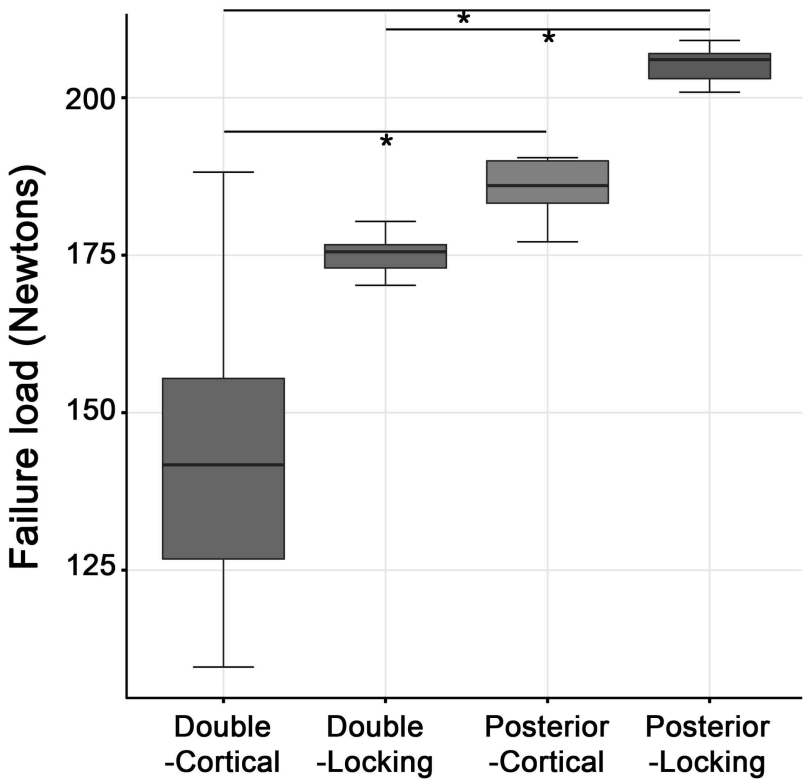

Figure 5. Maximum load in the four groups.

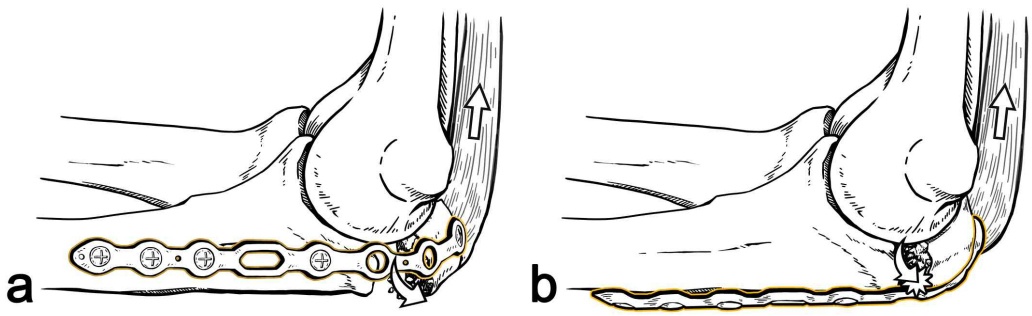

Figure 6. Effect of plate position on the rotational displacement of the triceps fragment. (A) A double-plate fixation can prevent distraction forces. However, its effects on rotational displacement are limited. (B) A posterior plate can effectively fix the triceps fragment against distraction and rotational forces.

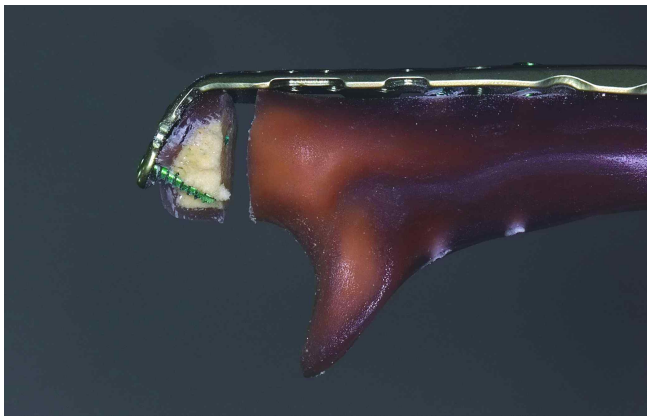

Figure 7. Catastrophic failure occurred at the load screw site in the PL group.

Supplemental data

	Cyclic_Loading_Test							Load_To_Failure_Test
	Gapping_During_Exercise	Displacement_After_Exercise						Failure_Load
		Anterior_Cortex_Pretest	Anterior_Cortex_Posttest	Anterior_Cotex_displacement	Posterior_Cotex_Pretest	Posterior_Cortex_Posttest	Posterior_Cotex_displacement	
DC	0.333	5.52	5.64	0.12	4.92	4.84	-0.08	150.279
DC	0.423	5.01	4.98	-0.03	4.87	5.03	0.16	148.587
DC	0.248	4.52	4.20	-0.32	5.11	5.32	0.21	170.884
DC	0.294	4.82	4.92	0.1	5.23	5.60	0.37	188.186
DC	0.477	4.89	5.20	0.31	5.01	5.11	0.1	112.470
DC	0.481	5.23	5.28	0.05	5.02	5.11	0.09	131.540
DC	0.584	5.54	5.51	-0.03	5.00	5.02	0.02	109.628
DC	0.492	5.18	5.10	-0.08	4.76	5.01	0.25	134.840
DL	0.190	5.03	5.10	0.07	5.00	5.12	0.12	176.257
DL	0.183	5.52	5.68	0.16	4.98	4.81	-0.17	170.218
DL	0.148	4.84	4.68	-0.16	5.21	5.48	0.27	173.335
DL	0.120	4.78	4.82	0.04	5.02	5.10	0.08	171.887
DL	0.177	4.62	4.68	0.06	5.68	5.62	-0.06	176.012
DL	0.189	5.60	5.69	0.09	5.40	5.60	0.2	177.879
DL	0.164	4.48	4.52	0.04	5.00	5.11	0.11	180.358
DL	0.211	4.69	4.81	0.12	5.34	5.42	0.08	175.046
PC	0.084	5.20	5.19	-0.01	5.01	4.98	-0.03	184.515
PC	0.078	5.60	5.50	-0.1	5.20	5.30	0.1	185.219
PC	0.101	5.84	5.92	0.08	4.98	4.84	-0.14	190.471
PC	0.097	5.43	5.49	0.06	5.10	5.11	0.01	177.124
PC	0.120	5.50	5.52	0.02	4.98	4.78	-0.2	179.487
PC	0.087	5.67	5.48	-0.19	4.70	4.99	0.29	186.876
PC	0.064	5.39	5.52	0.13	4.80	5.10	0.3	189.797
PC	0.050	5.58	5.80	0.22	4.90	4.78	-0.12	190.475
PL	0.167	5.11	5.29	0.18	5.00	5.01	0.01	205.994
PL	0.074	4.98	4.92	-0.06	4.70	4.26	-0.44	202.948
PL	0.155	4.70	4.72	0.02	5.32	5.11	-0.21	206.847
PL	0.089	4.80	4.68	-0.12	5.28	5.38	0.1	203.049
PL	0.099	4.64	4.68	0.04	5.40	5.60	0.2	207.487
PL	0.102	4.20	4.30	0.1	5.50	5.52	0.02	206.084
PL	0.086	5.50	5.52	0.02	5.01	4.90	-0.11	209.088
PL	0.174	5.64	5.80	0.16	4.79	4.99	0.2	200.874

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국문초록

작은 삼두근 골절편을 가지는 주두 분쇄골절에서 금속판 위치에 따른 생역학적 안정성 비교

서론

주관절의 신전기능 보존을 위해 주두 골절에서 삼두근 절편을 고정하는 것은 중요하다. 하지만 임상상황에서 금속판 고정시 삼두근 절편이 작아 몇 개의 나사만 고정할 수 밖에 없는 상황을 자주 만난다. 이 연구의 목적은 합성골 주두분쇄골절 모델에서 삼두근 절편에 2개의 나사만 삽입하였을 때 이중금속판과 후방금속판의 안정성을 생역학적으로 비교하는 것이다.

방법

합성척골의 주두부위에 5mm 골 결손을 만들어 분쇄골절과 유사한 상황을 모사하였다. 이중금속판과 후방금속판에 피질골나사와 잠김나사를 각각 사용하여 4개의 실험군을 설정하였으며, 사전실험을 통해 각 그룹당 8개의 시편을 만들었다. 가벼운 운동시의 안정성을 확인하기 위해 5N에서 50N의 힘을 500번 가하는 순환하중검사를 수행하여 검사중 미세운동과 검사 전후의 골절간격 변화를 측정하였다. 각 고정법의 최대고정력을 확인하기 위해 0N에서 분당 1mm씩 골절면이 벌어지도록 힘을 가하며 시료의 파단 혹은 2mm 이상 벌어질 때까지의 최대 힘을 측정하였다.

결과

모든 그룹은 순환하중검사 중 0.5mm 이내의 미세운동을 보여 비교적 안정적이었고 검사 전후의 골절간격의 유의미한 차이는 없었다. 하지만 순

환하중검사 중 미세운동의 그룹간 차이는 있었는데, 후방금속판-피질골나사가 0.09 ± 0.02mm로 가장 안정적이었고 이중금속판-피질골나사가 0.42 ± 0.11mm로 가장 불안정하였다($p < 0.001$). 최대고정력은 후방금속판-잠김나사군이 가장 안정적이었고(205.3 ± 2.8N), 이중금속판-피질골나사군이 가장 불안정하였다(143.3 ± 27.1N)($p < 0.001$).

결론

합성골을 이용한 주두분쇄골절에서 2개의 삼두근 나사를 사용하였을 경우 이중금속판과 후방금속판은 가벼운 운동시에는 안정적이지만 후방금속판이 이중금속판에 비하여 더 강한 고정력을 보였다. 따라서 주두분쇄골절이 심하여 적은 삼두근 나사를 사용해야할 경우 이중금속판보다 후방금속판이 임상적으로 더 유리할 것으로 예상된다.

주요어 : 주두, 분쇄골절, 금속판 고정, 생역학적 분석,
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