Pull-out strength of suture anchor and torque of buddy anchor for an osteoporotic humeral head in rotator cuff repair: Parallel versus divergent insertion

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ABSTRACT

Pull-out Strength of Suture Anchor and Torque of Buddy Anchor for an Osteoporotic Humeral Head in Rotator Cuff Repair: Parallel Versus Divergent Insertion

Abstract
Background: The buddy anchor technique is useful to reinforce loose anchors in the osteoporotic humeral head during arthroscopic rotator cuff repair. However, theoretical parallel insertion of the buddy anchor to index a loose anchor is challenging in arthroscopy and can widen the entry site and decrease structural integrity.

Purpose: To investigate and compare the biomechanical stability between 2 buddy anchor insertion techniques (parallel insertion vs divergent insertion) in the osteoporotic humeral head.

Study design: Controlled laboratory study.

Methods: A total of 24 paired fresh-frozen cadaveric shoulders were used, and each pair was randomly assigned to either the parallel insertion group or the divergent insertion group. In the parallel insertion group, the buddy anchor was inserted parallel to the index loose anchor. In the divergent insertion group, the buddy anchor was inserted at a 20° angle in the medial direction to the index loose anchor. The insertion torque of the buddy anchor and ultimate pull-out strength of the index anchor were measured and compared between the 2 groups.

Results: The mean maximum insertion torque was significantly higher in the parallel insertion group (16.1 ± 1.8 cN·m) compared with the divergent insertion group (12.0 ± 1.5 cN·m) ($P < .001$). The mean ultimate pull-out strength was significantly higher with divergent insertion (192.2 ± 28.6 N) than with parallel insertion (147.7 ± 23.6 N) ($P < .001$).

Conclusion: For application of the buddy anchor system in the cadaveric osteoporotic humeral bone model, divergent insertion showed better ultimate pull-out strength than conventional parallel insertion, despite inferior maximum insertion torque.

Clinical relevance: The results of this study widen the applicability and accessibility for the buddy anchor system.

Keywords: buddy anchor; divergent insertion; loose anchor; osteoporotic bone; parallel insertion; rotator cuff repair.

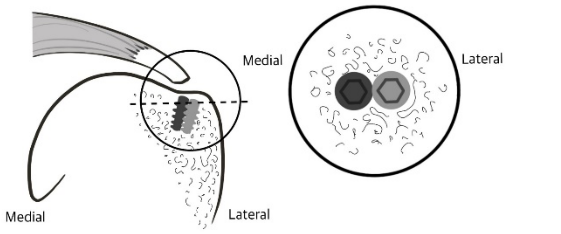
1. INTRODUCTION

As population aging progresses and a growing number of elderly people remain active, the volume of rotator cuff repairs is increasing[5,9]. It is common to encounter older patients with osteoporosis suffering from rotator cuff tears. In the operation field for arthroscopic rotator cuff repair, it is sometimes hard to obtain solid fixation of the suture anchors due to poor bone quality. These loose anchors are likely to be associated with migration or pull-out, which lead to suboptimal clinical outcomes[1,7,10].

To overcome this issue, many investigators have developed ways to reinforce loose anchors using compaction bone grafting, a rescue anchor technique, or a buddy anchor technique (or buddy system)[6]. Among these techniques, the buddy anchor technique is used to salvage a loose anchor migrated above the surface of the bone due to poor bone quality. With re-advancement of the anchor, a second anchor is inserted adjacent to the loose anchor to create an interference fit and subsequent higher pullout strength[2,8].

Theoretically, to acquire the optimal interference fit, perfect parallel insertion of the two anchors is required. However, perfect parallelism is not feasible during real arthroscopic surgery. Although a starter hole for the second anchor is created as an undersized socket in half-depth using an awl[6], particularly in the setting of osteoporosis, the entry easily widens during parallel insertion of the second anchor for the interference fit, which, paradoxically, results in loss of stability. Here, rather than achieving interference fit between the two anchors, we tried to insert a second anchor in a divergent direction, expecting it to block the pullout of the loose index anchor at the entry site. Interestingly, after divergent insertion of the buddy anchor, stability or holding strength of the index anchor improved more than expected despite suboptimal interference fit between the two anchors.

The purpose this study was to investigate and compare the biomechanical stability between two buddy anchor insertion techniques (parallel insertion versus divergent insertion) in the setting of the osteoporotic humeral head. We hypothesized that divergent insertion of the buddy anchor would have comparable or higher biomechanical strength than conventional parallel insertion of the buddy anchor



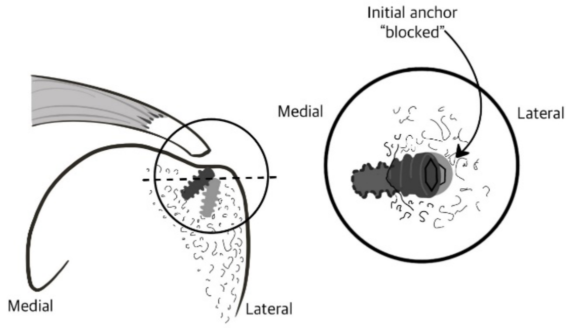


Figure 1 (A) Buddy anchor with parallel insertion. (B) Buddy anchor with convergent insertion.

2. Method

2.1 Specimen & bone mineral density evaluation

Twenty-four paired fresh-frozen cadaveric proximal humeri were used, and each pair was randomly assigned to either the parallel insertion group or the divergent insertion group. All specimens were preserved frozen at -20 °C and thawed at room temperature for 24 hours. All soft tissues were removed, and the humeri were cut 22 cm from the head. Specimens with a previous surgical history or gross bone abnormalities were excluded. The trabecular bone mineral density (BMD) of greater tuberosity was measured using quantitative computed tomography (qCT, LightSpeed VCT 64, GE Healthcare, Milwaukee, WI). For this measurement, each humerus was fixed horizontally, with the top of the greater tuberosity in the 12 o' clock position[15,16], and an axial scan (30 slices, with 3 mm slice thickness over range of 8 to 12 cm at 120 kV and 150 mAs) was performed. A region of interest was defined as a 10 mm × 10 mm rectangle on coronal and sagittal scans and as a 10-mm-diameter circle on axial scans just medial to the footprint of the rotator cuff where the anchors were to be inserted.

All specimens were sourced from our institution with consent. Our institutional review board approved this study and waived the requirement for informed consent.

2.2 Anchor insertion & measurement of insertion torque

The humerus was fixed with polymethacrylate in a customized jig. For simulation of a loose anchor in the operative field, we created an oversized pilot hole for the 4.5 mm anchor (CrossFT® 4.5 mm Suture Anchor, ConMed, Utica, NY) using an awl for a 5.5 mm anchor. The pilot hole was created at a 45° angle to the surface of the greater tuberosity[3], and an index anchor was inserted. On the same entry and just adjacent to the index anchor, a pilot hole for the buddy anchor was created using an awl for a 3.7 mm anchor. In the parallel insertion group, the buddy anchor was inserted in the parallel direction of the index anchor (Fig. 1A). In the divergent insertion group, the buddy anchor was inserted at a 20° angle to the index anchor in the medial direction (Fig. 1B). When the buddy anchor was inserted through about half of the depth of the hole, a torque wrench (BTG36CN-S; TOHNICHI MFG. CO. Tokyo, Japan) was applied to the rod of the suture anchor in situ. Then, the maximum torque during the insertion of the other rest was measured (Fig. 2).

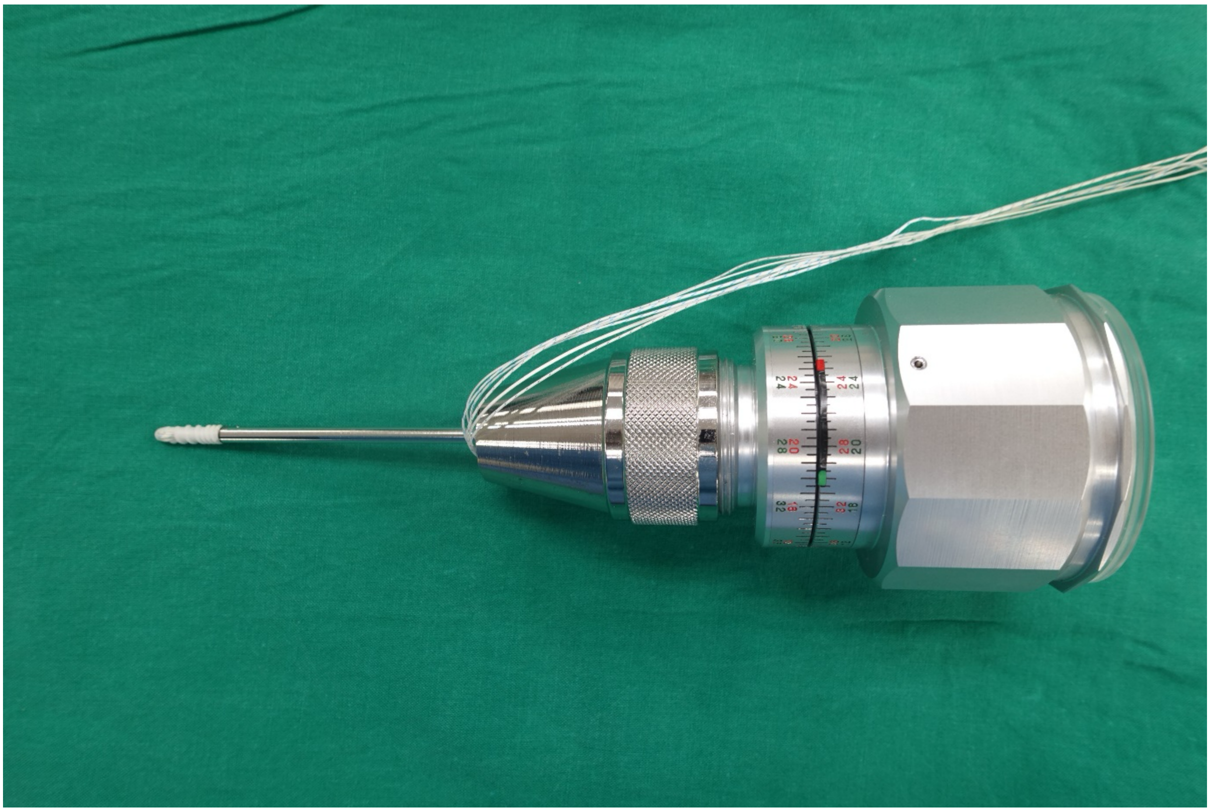


Figure 2 A torque wrench (BTG36CN-S; TOHNICHI MFG. CO. Tokyo, Japan) was applied to the rod of the suture. The actual measurement of torque was performed in situ without pulling the anchor immediately after inserting half of the length of the anchor**.**

2.3 Pullout strength

To simulate the physiologic pull of the supraspinatus tendon, sutures were pulled at 90° to the axis of the anchor[8,12,14] (Fig.3). The sutures were fixed 20 cm from the crosshead of the Instron (Instron 3366, Instron Co., Ltd, Norwood, MA) and preloaded to 10N to ensure full engagement of the anchors to the bone. With an extension rate of 20 mm/min, the anchors were loaded to ultimate tensile strength and maximum tensile load before pullout, which was defined as pullout strength.

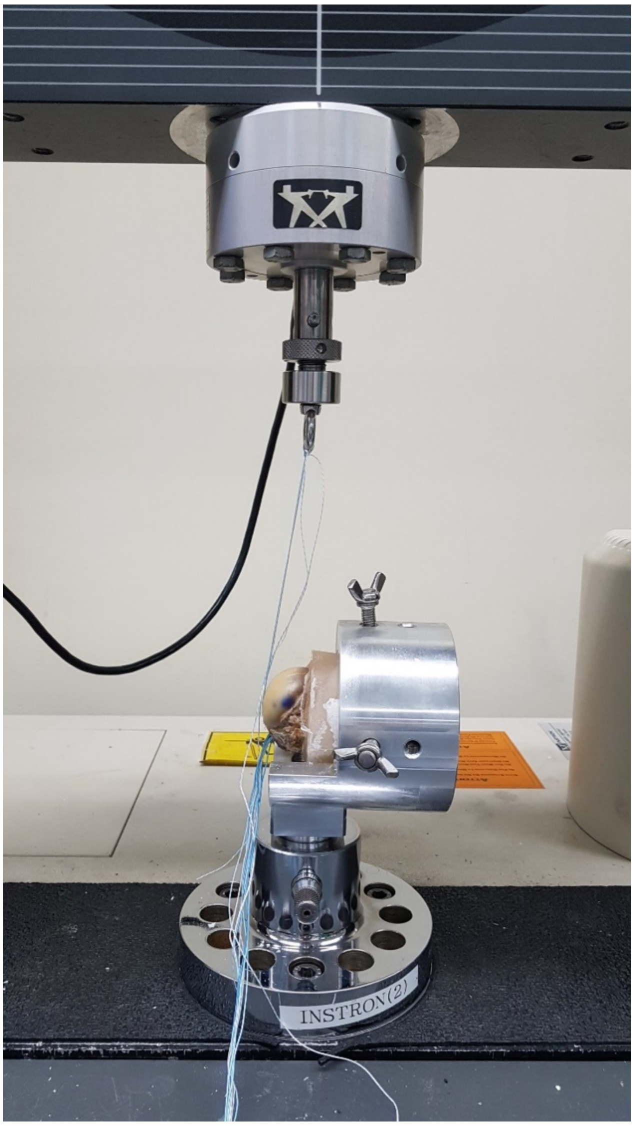


Figure 3 Pulling the sutures with the Instron (Instron 3366, Instron Co., Ltd, Norwood, MA)

2.4 Statistical test

A power analysis was performed in the setting of $\beta = 0.1$ and $\alpha = 0.05$ using the data from our pilot study. Because there was no human cadaveric study on this topic, a pilot study was performed with three paired humeri to compare the pullout strength of both groups. We found a pullout strength of

142.3 ± 11.8 N for the parallel group and 184.3 ± 37.7 N for the divergent group, and the sample size was calculated to be at least 11 samples per group. For this study, we performed the test with 12 specimens in each group.
The Wilcoxon signed-rank test was used to compare BMD, insertion torque, and pullout strength. The Spearman's rank correlation coefficient was calculated to evaluate correlation between groups. Statistical significance was set as $p < 0.05$. Statistical analyses were performed using R statistical software (version 4.0.4; R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Twelve pairs of intact humeri with a mean age of 70.5 years were used for each group. Seven specimens were male, and the other five specimens were female. The mean trabecular BMD was 31.5 mg/cc for the parallel group and 32.9 mg/cc for the divergent group; these results did not show a significant difference (Table 1).

	Parallel insertion	Divergent insertion	P value
Age	70.5 ± 6.6		
Sex (M/F)	7/5		
BMD (mg/cc)	31.5 ± 7.0	32.9 ± 6.6	0.622
Torque (cN·m)	16.1 ± 1.8	12.0 ± 1.5	<0.001
Pullout strength (N)	147.7 ± 23.6	192.2 ± 28.6	<0.001

Table 1 Group comparisons BMD, bone mineral density; F, female; M, male.

The mean maximum torque was significantly higher in the parallel insertion (16.1 cN·m) group than in the divergent insertion (12.0 cN·m) (Fig. 4). Regarding the ultimate pullout strength, divergent insertion demonstrated a significantly higher load to failure than did parallel insertion (192.2 N in divergent insertion, 147.7 N in parallel insertion; Fig. 5).

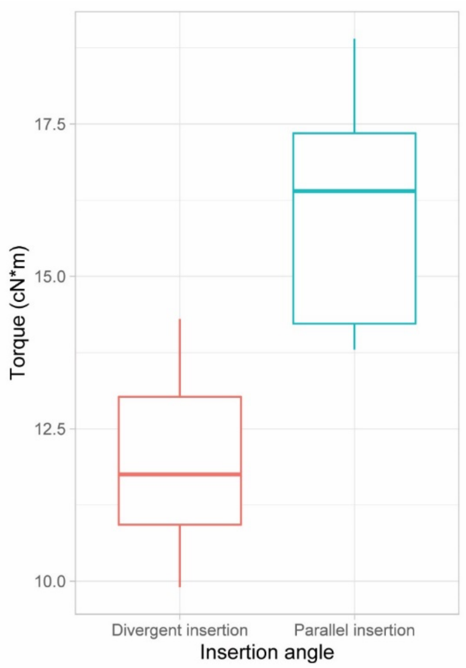


Figure 4 Comparison of the maximum torque between divergent and parallel insertion during the remaining halflength of the anchor.

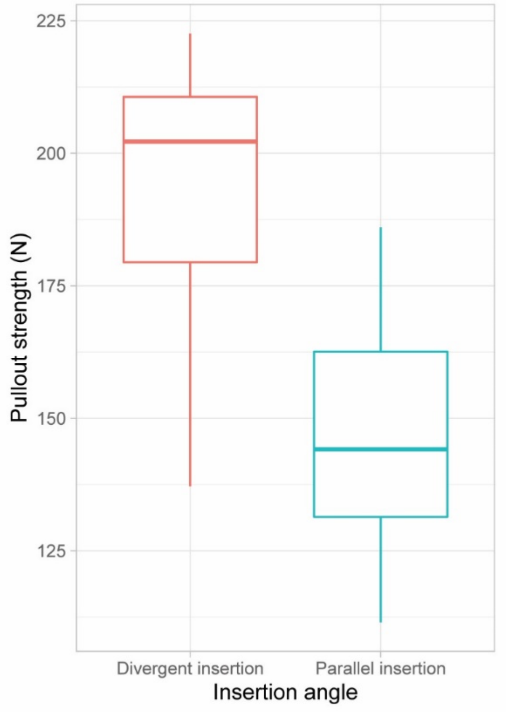


Figure 5 Comparison of the ultimate pull-out strength between divergent and parallel insertion.

The maximum torque of insertion was correlated to the pullout strength in group analysis. Spearman's rank correlation rho was 0.752 ($p = 0.005$) for the parallel insertion group and 0.853 ($p < 0.001$) for the divergent group (Fig. 6)

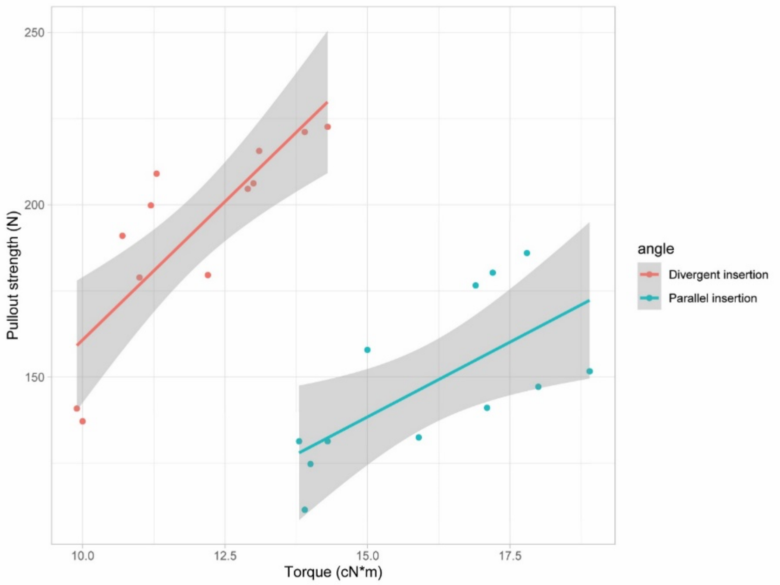


Figure 6 Relationship between insertion torque and pull-out strength. The maximum torque during insertion was significantly correlated with the pull-out strength in both divergent and parallel insertion.

4. Discussion

As we hypothesized, divergent insertion of the buddy anchor yielded significantly higher ultimate pull-out strength than parallel insertion in setting the osteoporotic humeral head; this was not consistent with the theoretical interference fit created in the buddy anchor system. Although the maximum torque measured during buddy anchor insertion was significantly correlated with the ultimate pullout strength in within-group analyses, the mean value of the maximum torque was significantly higher in parallel insertion of the buddy, which was contrary to the ultimate pullout strength.

As reported in earlier studies, if the suture anchors cannot maintain solid fixation in the humeral head during or after insertion in rotator cuff repair, the outcomes are unfavorable[1,7,10]. To avoid this complication, there have been trials and efforts to obtain optimal fixation regarding insertion angle, location, and distance between suture anchors[11,13,16]. Nonetheless, in patients with osteoporosis, the inserted suture anchors were likely to be unstable. Thus, Brady et al. introduced the buddy anchor technique as a salvage technique[2].

When inserting the suture anchor in the arthroscopic field, solidity of fixation is usually detected by the surgeon’s hand through torque loaded during anchor insertion; typically, torque correlates with pullout strength of the suture anchor. Chun et al.[4] reported that torque during insertion of the anchor is related to pullout strength of the anchor, and the current study showed the same correlation between torque and pullout strength by within-group analysis. Furthermore, the maximum torque was higher in parallel insertion of the buddy anchor, as indicated by the theoretical interference fit. Based on the current study, torque appears to depend on the interference fit created by parallel insertion of the buddy anchor. However, despite inferior torque during divergent insertion, greater pullout strength was achieved compared to that of parallel insertion. The blocking effect created by divergent insertion seemed to overcome the interference fit created by parallel insertion.

Typically, the need for a buddy anchor is determined based on low holding strength of the inserted anchor when pulling the sutures. As reported by Burkhart and Denard, the essential mechanism of the buddy anchor system is reinforcement of pullout strength by interference fit. To achieve optimal interference fit, the buddy anchor should be inserted parallel to the index anchor. However, in the real arthroscopic field, at least to the authors, parallel insertion of the buddy anchor can be challenging; furthermore, despite great care, the entry hole is easily widened during parallel insertion. Thus, instead of interference fit, we tried to insert the buddy anchor over the first primary anchor in a divergent direction, expecting a blocking effect by the buddy anchor. This divergent insertion was much easier and did not widen the entry of the hole during insertion.

To verify the effect of the buddy anchor, the osteoporotic bone model or loose anchor model should be established first. Previous biomechanical studies compared the buddy anchor system with the single anchor[2 8]. The current study excluded experiments with single-anchor insertion because we simulated an actual loose anchor model. In the loose anchor model, the loose single anchor would not require any torque during insertion and could be pulled out without any resistance. Brady et al. used polyurethane foam to resemble osteoporotic bone. In another study, Horoz et al.[8] predrilled ovine bone before inserting anchors that did not need predrilling in routine use to weaken the holding strength of the anchors. Although this osteoporotic bone model was established earlier by Uruc et al.[17], considering that even a single anchor alone yielded more than 200N for ultimate failure load, we are not sure whether this model really represents an osteoporotic model or a loosening anchor situation. In the current study, we created an oversized pilot hole that was larger than the anchor to simulate an osteoporotic model closer to a loose anchor that did not have any holding strength provided by the index anchor alone in the humeral head.

5. Limitations

This study has several limitations. First, thread height and screw size vary according to product. As different anchor products have different outcomes, caution is warranted. The holding strength created by interference fit will be different based on thread height and size differences of the anchors. Second, we did not confirm in cross-sectional CT images that the divergent anchors were truly inserted at 20° degrees as intended. Third, the divergent angle of 20° was arbitrarily determined according to the author’s preference and convenience in the arthroscopic field. Thus, we are not certain whether this 20° angle is optimal for creating a blocking effect by divergent insertion of the buddy anchor. Further studies are necessary to determine the optimal angle of insertion. Fourth, since this study was performed using cadaveric specimens, it may not fully represent the conditions of patients with actual osteoporosis. Fifth, in this study, the buddy anchor was inserted in a medial position relative to the index anchor, which may add technical challenges during surgery.

Additionally, the use of a buddy anchor itself could pose potential risks to vascularity due to the increased number of anchors.

6. Conclusion

For application of the buddy anchor system in an osteoporotic humeral bone model created by an oversized pilot hole, divergent insertion showed better ultimate pullout strength than conventional parallel insertion despite inferior maximum insertion torque.

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Abstract in Korean

회전근개 수술에서 골다공증성 상완골두에 대한 봉합 앵커의 뽑힘 강도 및 버디 앵커의 토크: 평행 삽입과 분산 삽입 비교

배경: 버디 앵커 기법은 관절경을 통한 회전근개 봉합 시 골다공증성 상완골두에서 고정력이 없는 앵커에 대처하는데 유용하다. 하지만 관절경 수술에서 고정력이 없는 앵커에 평행하게 버디 앵커를 삽입하는 것은 실질적으로 어려우며, 이는 진입 지점을 넓히고 구조적 강도를 약화시킬 가능성이 있다.

목적: 골다공증성 상완골두에서 두 가지 버디 앵커 삽입 기법(평행 삽입 대 분산 삽입)의 생체역학적 안정성을 조사하고 비교하는 것.

방법: 24쌍의 사체 어깨를 사용하였으며, 각각의 쌍을 무작위로 평행 삽입 그룹 또는 분산 삽입 그룹에 할당하였다. 평행 삽입 그룹에서는 버디 앵커를 앵커와 평행하게 삽입하였고, 분산 삽입 그룹에서는 버디 앵커를 앵커의 중간 방향으로 20도 각도로 삽입하였다. 버디 앵커의 삽입 토크와 고정력을 잃은 느슨한 앵커의 최종 견인 강도를 측정하고 두 그룹 간의 결과를 비교하였다.

결과: 평균 최대 삽입 토크는 평행 삽입 그룹(16.1 ± 1.8 cN·m, 범위 13.8-18.9)이 분산 삽입 그룹(12.0 ± 1.5 cN·m, 범위 9.9-14.3)보다 유의하게 높았다($p < 0.001$). 반면, 최종 견인 강도는 분산 삽입(192.2 ± 28.6 N, 범위 137.2-222.6)이 평행 삽입(147.7 ± 23.6 N, 범위 111.5-186.0)보다 유의하게 높았다($p < 0.001$).

결론: 골다공증성 상완골 모델에서 버디 앵커 적용 시, 비록 최대 삽입 토크는 낮았지만 분산 삽입이 평행 삽입에 비해 더 나은 최종 견인 강도를 보여주었다.

핵심되는 말 : 버디 앵커, 회전근개 수술, 골다공증성 뼈, 분산 삽입, 평행 삽입